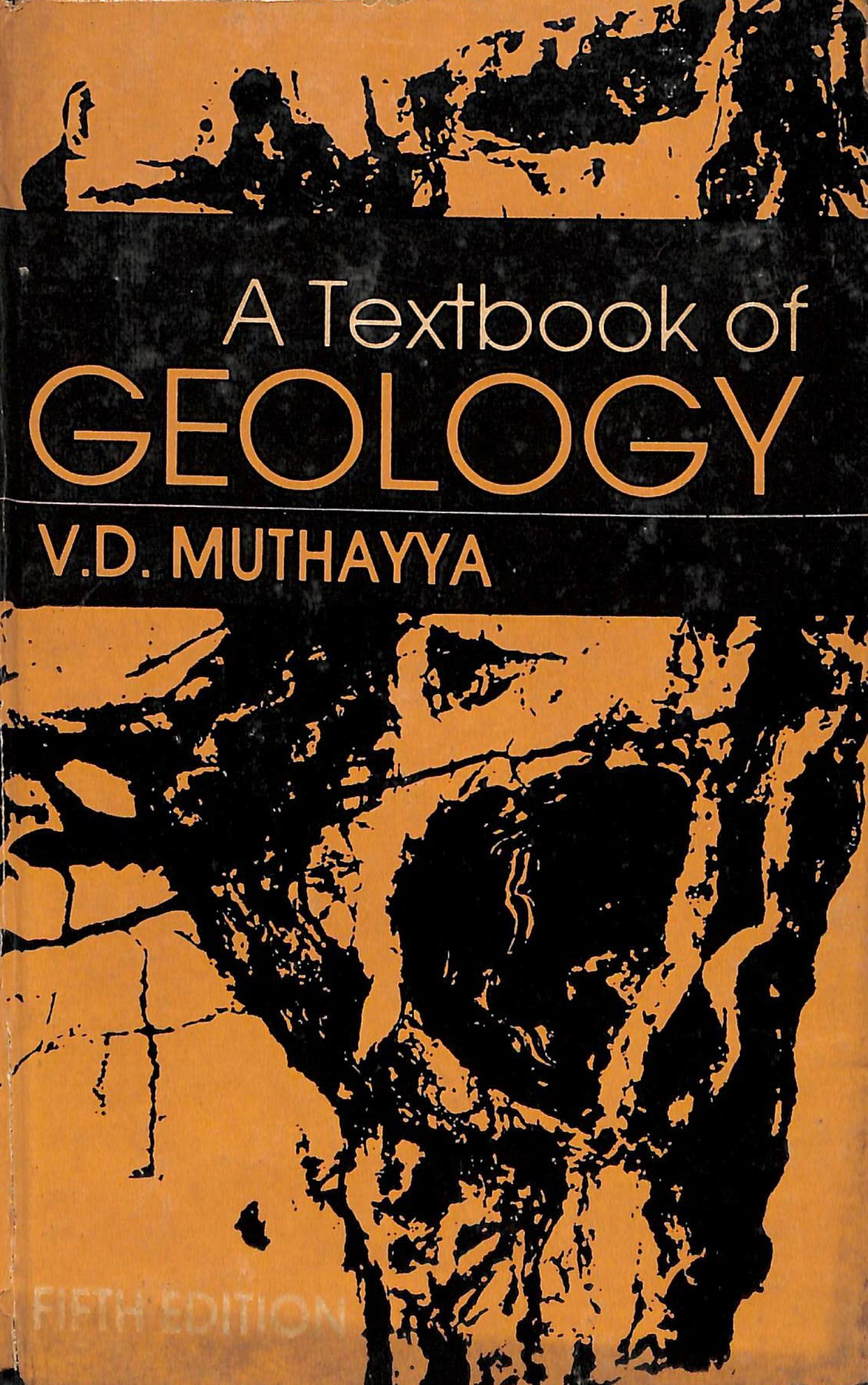
A Textbook of GEOLOGY

V.D. MUTHAYYA



FIFTH EDITION

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A TEXT BOOK OF GEOLOGY

(For the use of Engineering & Technology students in Indian Universities)

Fifth Edition

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DEDICATION

This book is dedicated to my Divine Master
Meivazhisalai Andavargal

(Founder of the Holy Order at Meivazhi Sabai in Pudukottai District in Tamil Nadu)

in eternal gratitude for revealing in us the Holy Spirit (Brahman) thus leading us from Death to Eternal Life.—thereby granting us the following prayer in Brihadaranyaka Upanishad—
MRITHYOR MA AMRITHAM GAMAYA

Preface to the Fifth Edition

A diamond which is well-cut is that much more brilliant than otherwise. Similarly, a text, which is modified by valuable suggestions, is that much more useful to students. I, therefore, profusely thank Professor S.K. Chadha, Head of the Department of Geology, Government G.M. Science College, Jammu and Kashmir, for his valuable suggestions, all of which, incorporated herein, have improved the text.

I have also included in this edition, three illustrations—Plate 1 between pages 162 and 163, and Plate 2 between pages 174 and 175, to make the text more vivid.

Meivazhisalai
January 1988

V. D. MUTHAYYA

Preface to the Fourth Edition

Publication of the new edition of a textbook that meets the requirements of students of geology in such varied courses as A.M.I.E., B.E. (Civil), B.E. (Metallurgy), B. Tech., Forest & Forest Rangers, B.A. (Geography), B.Sc. (Engineering). B.Sc. (Ceramics), B.Sc. (Geography), etc., needs no justification.

The author has read the entire text once again, with a view to find out how best he can make it more useful to the students for whom it is intended. This he has done by providing in the Appendix some additional matter to Chapters III, IV and VII. The additional matter to Chapter III, given in the Appendix, may be read before reading the Chapter. It will serve as a historical introduction to Mineralogy. The schematic diagrams given in the end and the matter under them will throw more light on the content of Chapter III. They should therefore be perused after reading Chapter III. The appendix to Chapter VI should be read after reading the chapter. It furnishes the minerals under various systems of mineral formation. Appendix to Chapter VII may be read before reading the chapter. It explains how a thorough knowledge of geology is necessary and advantageous to a Civil Engineer.

While thanking the many friends and colleagues for their invaluable assistance in making this book better, the author has to make a special mention of Shri Satis Kumar Chadha, Lecturer in Geology, Government G.M. Science College, Jammu & Kashmir, whose criticisms and suggestions have been of great help in improving the text.

The author gratefully thanks Dr. K.A.V. Pandalai, Director, I.I.T., Madras, for his permission to bring out this new edition, Dr. K.S. Sankaran, Head of the Department of Civil Engineering, I.I.T., Madras, for his kind encouragement and Dr. N. Leelananda Rao, Head of the Department of Geology and Geophysics, University of Madras, for his help and guidance.

The author expresses his sincere thanks to the publishers, M/s. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, for their great efforts in bringing out this latest edition, in a nice manner.

AUTHOR

Preface to the Third Edition

In this new edition some modifications and additions have been made particularly in the chapters on Physical Geology, Mineralogy and Engineering Geology for improvement of the text. A distinctive feature of this edition is the new set of questions that appear at the end of chapters II, III, IV, and VI. There are two sets of questions, Group A and Group B. The questions in Group A, as a self quiz may help the student to test his understanding of the topics. The questions in Group B are based on the pattern of University examinations.

The author expresses his thanks and gratitude to Dr. A. Ramachandran, Director, I.I.T., Madras, for granting him the necessary permission to publish this edition and to Dr. P.C. Varghese, Head of the Department of Civil Engineering, I.I.T., Madras, for his kind encouragement. Many thanks are due to Dr. K.S. Sankaran, Dr. D.J. Victor and Sri C. Ganapathy Chettiar for their helpful suggestions.

For the help rendered in reading the manuscript, proof corrections and in the preparation of new illustrations, the author owes his thanks to Sri S.P. Subramanian and Sri K.N. Ramamurthy. His grateful thanks are also due to many others for offering suggestions and to the Publishers, Oxford and IBH Publishing Co. Pvt. Ltd., Calcutta for their kind courtesy and interest shown in bringing out this volume.

Madras
21-8-1968

AUTHOR

Preface to the Second Edition

This new edition is brought out with a slight rearrangement of the chapters and with more information and illustrations suitably incorporated in the chapters on Indian stratigraphy and Engineering geology. At the end, an index has also been added for the convenience of readers.

Special thanks for the photographs included in this volume must be given to the Director General, Geological Survey of India, Calcutta, Shri M.S. Jagadeesan and Sri G. Trasi. Many friends and colleagues were helpful in the preparation of this edition and author's most sincere thanks are due to them.

A word of appreciation has to be added about the artist Sri P. Rishikesan who has designed the cover page in a delightful and thoughtful manner presenting the architecture of Man and Nature appropriate to the title of this text.

Madras
27-9-1965

AUTHOR

Preface to the First Edition

Since August 1947, with the attainment of freedom, our responsibility for industrialisation has tremendously increased calling for the nation's entire effort and tapping of all available resources. Engineers and technologists have a major part to play in this tremendous task of building a new India. A proper understanding of the subject of Geology by the engineers and technologists will greatly help in the successful exploitation and conservation of our country's mineral resources. Otherwise in the enthusiasm of constructing our river valley projects, bridges railways, highways etc., the minerals may be wasted or their occurrences may be lost sight of.

The progress of human civilisation has been greatly dependent on the knowledge gained by Man of the earth's resources and the archaeologists have aptly described the various stages of human progress at stone age, bronze age and iron age. These emphasise the importance of the earth's materials.

This book presents in a concise form, the subject of Geology as drafted in syllabi of engineering and technological courses in Indian Universities. In writing this book, the extensive literature available from the English, American and Indian publications, to which reference has been made at the end has been greatly useful and the author expresses his gratitude to the authors and publishers of the books.

The author is greatly indebted to Sri N.S. Krishnaswamy, Principal Government College of Technology, Coimbatore for his suggestion to write this book, Sri P.R. Ramaswamy, Professor of Civil Engineering for his kind encouragement, his friend and colleague Sri N. Veerabadhu who has spared no pains in the preparation of the various illustrations included in this book and for his valuable guidance and help in making this volume, and other colleagues who have helped in bringing out this publication.

The author is highly grateful to Sri P.R. Ramakrishnan, Principal, Coimbatore Institute of Technology and Managing Director, Nava India Coimbatore for publishing this book and bringing it into such an attractive volume.

Coimbatore
1958

AUTHOR

CONTENTS

The hills are shadows and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go.

— Lord Tennyson



Courtesy of Geological Survey of India.

Valley Glacier - Sonapani Glacier - LAHUL - PUNJAB

CHAPTER I

INTRODUCTION

Geology, the science of the earth is a fascinating branch of study in Natural Science. It is fascinating because it explains to us the development of topographical scenery on the surface of the land such as the high mountains (the Himalayas, the Alps etc.,) vast plains, volcanoes, waterfalls, grand canyons and coral reefs. It is important and useful as it reveals to us the earth's hidden treasure and gives us knowledge of the occurrence of minerals which form the invaluable raw materials in different industries. The minerals when once removed can never be replenished. Hence the conservation of minerals and the proper utilisation of minerals should receive the utmost consideration. The minerals which form the important natural wealth of a country should not be wasted by unscientific methods of mining and carelessness. So some knowledge of minerals is essential to the mining engineer, metallurgist, chemist and industrialist. Geological knowledge is necessary to the civil engineer in carrying out safely and successfully the various engineering projects like the construction of dams, tunnels and mountain roads, and in selecting suitable rocks for building stones and road metals.

Geology is that branch of Science which treats of the earth comprehensively with regard to its composition, structure and history. Its study is of wide extent and embraces a great variety of subjects which are commonly studied under the following different heads :—

Physical Geology deals with the various principles and processes that are operating on the surface of the earth modifying its relief features from time to time.

Mineralogy deals with minerals which form the units of rocks which constitute the earth's crust.

Petrology treats of the rocks which form the component parts of the earth's crust.

Structural Geology deals with the arrangements of the structural relations of rocks and particularly with their relations to one another.

Palaeontology is the study of the remains of ancient life that are found in rocks.

Historical Geology or Stratigraphy is the study of the history of the earth as shown by its rocks and particularly the record of events that is revealed in the rocks and by the relations of rock formations to one another.

Economic Geology treats of the occurrence, origin and distribution of the materials of the earth that are valuable to Man and the application of geological facts and principles in industry and engineering fields.

For a proper understanding of the science of Geology, some knowledge of its various branches mentioned above, is quite necessary and essential.

PHYSICAL GEOLOGY

The picturesque scenery presented by the landscapes on the earth's surface always captivate one's mind during a journey across a country. The mountains and valleys occasionally studded with waterfalls and cascades and the plains and plateaus with rivers and lakes are some of the familiar earth features which have been a source of delight to travellers on land. The world reknown landscapes such as the high Himalayan and Alpine ranges, the Grand Canyon of Colorado, the Niagara Waterfalls, coral islands of the Pacific Ocean the volcanic mountains like Vesuvius in Europe and Fujiyama in Japan are well known for their scenic beauty and grandeur.

The study of these landforms with regard to their structure and origin has made us aware of the various agencies at work on the surface of the earth. They are wind, running water, moving ice, etc. which are described as natural architects.

This branch of Geology which explains the various processes that are operating on the earth's surface and the development of different kinds of landforms is known as Physical Geology. These natural agencies are divided into two kinds.

1. Those which derive their energy fron. sources exterior to the earth chiefly from sun. They are known as external agencies e.g., atmosphere, rainfall and streams, snow and ice, lakes, ocean and organic life.

2. Those which derive their energy from source interior to the earth. They are known as internal agencies, e.g., earthquakes, volcanoes and mountain building movements.

ATMOSPHERE AND ITS WORK

Weathering: The process which involves breaking up and decay oı rock by wind aided by water and heat of the sun is known as weathering. Weathering is brought about by two sub-processes, disintegration and decomposition. Disintegration is otherwise known as mechanical weathering, as this process causes mechanical disruption of the rocks. Decomposition is otherwise

known as chemical weathering as this causes decay or rotting of the rocks due to chemical reaction. It is difficult to distinguish them separately. They go hand in hand. Disintegration facilitates the decomposition since the chemical agents can attack each newly made fragment from all sides simultaneously.

Effects of Weathering on Rocks and its Constituents. Rocks exposed at earth's surface consist of various minerals, and these react with the chemical agents of weathering differently and at very different rates. When felspars decompose the chief product is kaolin or clay which is of great importance, because it plays a great part in the formation of soils. The following reaction takes place.

Orthoclase + Water + Carbon dioxide = Kaolin + Quartz + Potassium carbonate

$$2KAlSi_3O_8 + 2H_2O + CO_2 = H_4Al_2Si_2O_9 + 4SiO_2 + K_2CO_3$$

Other common minerals that contain aluminium also yield clay when they are decomposed. Several of these minerals contain some iron and commonly form limonite (hydrous oxide of iron) and thus clay acquires a yellowish or reddish colour.

According to the size of particles which compose the broken and disintegrated rock, the following gradations are recognised. Pieces of rock from the size of a small melon up are termed boulders; those larger than peas gravel; those smaller than peas which do not cohere when wet, sand; and the finest material which can be carried by wind is dust and the last generally coheres when wet and is termed silt, mud or clay according to its character. Ordinary soils composed of variable mixtures of sand and these finer materials. We may roughly classify them into the following groups:

Sand—Composed of sand grains mostly quartz without clay.

Loam—Mixture of sand and clay.

Clay—The finest material, mostly kaolin without sand.

The red and yellow colour which many soils possess are due to hydrous oxide of iron produced by decay of minerals. The black colour seen in soils, is due to carbonaceous material resulting from decomposition of vegetation. This substance is known as humus.

Weathering is of vital importance to the human race because it produces soils, the basis of all life on land. Thus the surface of the earth may be divided into 3 divisions, bed rock, sub-soil and soil.

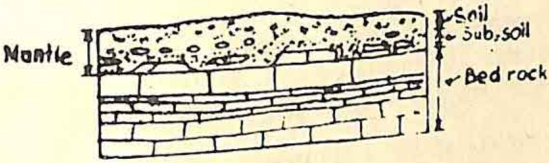


Fig. 1.

Exfoliation: In arid regions the rocks are heated to a high temperature during the day. Rapid cooling is also characteristic of these arid countries. The unequal expansion and contraction of the mineral constituents of the rock produce disintegration of the rock, itself. The rock sometimes is found to break off into concentric shells. This process is known as exfoliation. Some chemical changes also effect such breaking of layers.

Talus: Accumulations of rock fragments of various sizes occurring at the base of cliff or steep slope is termed talus. These are formed due to rolling down of weathered materials by the action of gravity. At times they form huge heaps or piles. A talus pile has a constant surface slope which ranges from 25 to 40°.

Spheroidal weathering: When weathering occurs, part of the disintegrated rock material is carried away by running water or any other transporting agent. Some of them are left on the surface of the bedrock as residual boulders. These boulders are then rounded off to spheroidal cores by the simultaneous attack of eroding agents on all sides. It is often seen that these boulders have an onion like structure. This kind of weathering is termed **spheroidal weathering.**

Erosional Work of the Wind: The wind erodes by deflation and abrasion. Loose particles of the mantle such as grains of sand and silt are picked up by moving air and carried from one place to another. This process is known as deflation. In their motion, some of the wind-driven particles strike against one another and against exposed bed rocks, with the result, additional particles are worn from the bed rock and from the original loose pieces. This process is known as wind abrasion, e.g. *dreikanter* or wind faceted pebbles (three edged). These deposits are formed due to action of wind in desert regions

Transportation of Soil or Sand by the Wind: The wind carries vast quantities of the material 10,000,000 to 100,000,000 tons in a single storm for distances as great as 2000 miles.

Atmosphere is not only destructive but also constructive in its work, e.g., *Eolian deposits* formed due to heavy sandstorm in arid regions (Eolias—God of wind in Greek mythology) and *Sand dunes* or hills made by wind-blown sand which are commonly seen all along the coast line in all parts of the world and in desert regions. Longitudinal ridge-like dunes are common where the winds are stronger.

Barchanes, the crescent shaped dunes are seen in interior regions where winds are less stronger.

Loess is extremly fine calcareous material transported by the wind from desert areas and arid regions liable to strong winds carrying much dust. Large stretches of wind-blown dust are found in Punjab, Kasamir, Sind and Baluchistan. Loess soil is extremely fertile. Loess deposits of China are the largest in the world and of thickness 31,000 ft.

Soil removal by the wind and also encroachment of sand on farm lands are disastrous to crops. Rajasthan, once a fertile land of many kingdoms, has been transformed into desert plains.

Desert Reclamation: 15 per cent of the earth's land surface is covered by deserts. In India the Rajasthan desert covers 80,000 sq. miles. If reclaimed, it holds great possibilities for agriculture and livestock industry. One of the methods of reclamation adopted is spraying of petroleum product on dune areas which holds the surface particles of sand against wind erosion. Sprayed around freshly planted seedlings in water bearing sand dunes, the stabilising oil helps them to retain moisture and resist wind in time to grow into healthy trees and thus bringing the desert back to life. These methods have been successfully tried in Bikaner in Rajasthan and Ramaswaram in South India with promising results. This helps greatly in rail-road construction and highway construction.

RAIN AND RUNNING WATER

A portion of the water which falls as rain evaporates and passes back into the atmosphere. A good portion of it gets

lodged in depressions and remains as lakes and ponds. A portion of it sinks into the soil and becomes sub-surface water and a portion of it flows down on the surface. That part is known as the run off and is about 1/3 of the rain that falls on the surface.

Formation of Streams : The run off, though it may start as a thin sheet of water, gradually concentrates into a fairly definite channel taking the shortest and steepest course downwards. Thus gradually run off takes the form of an organised stream and becomes a fluvial agent of erosion.

Fluvial erosion consists of four sub-processes: (1) Hydraulic action, (2) Abrasion (3) Solution and (4) Transportation.

Hydraulic action : The inherent force of water is capable of lifting up and moving loose material. This action of water is termed hydraulic action.

Abrasion can be defined as the mechanical wear of one rock with another. This is caused by friction between rock fragments moving with the stream and rock fragments or solid rocks in the stream bed.

Solution : No stream water is free from substance in solution. The rocks that are most easily soluble are the limestones. Even those rocks which are not easily soluble are gradually affected by acid bearing stream water.

Transportation : Fluvial transportation is largely accompanied by hydraulic action.

Rivers : The work performed by rivers may be placed under three heads: erosion, transportation and deposition. The work of a stream is accomplished chiefly by means of the bottom load consisting of sand, pebbles and silt, which it sweeps along near the bottom of the stream. With these as tools it grinds and rasps the rocks of its bed.

Study of the land surface of the earth has shown us that they are not permanent geological features and are ever changing the face of the earth. As the process of erosion is continued, three different stages are distinguished, i.e. youth, maturity and old age, and

topographic forms characteristic of these stages may be recognised in modern landscapes. Thus there is the steep-sided valley of the

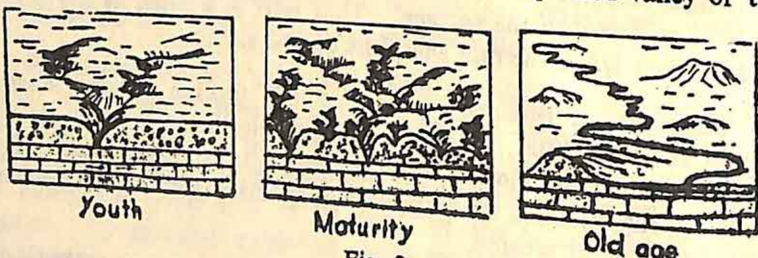


Fig. 2.

youthful stream, the broader valley and deeply dissected landscape of the more mature river system and the flat *meandering* course of a stream in old age. Rivers in their old age attain a stage when they can no longer excavate their bed rocks and the erosion ceases. This stage is known as *base level of erosion*. In course of ages the valley sides themselves are also levelled and the final result is a *peneplain*.

The course of a river may be divided into three portions, viz., the upper or mountain portion, middle or plains course and the lower or deltaic part. The upper course of a river is characterised by its waterfalls, *cascades* and *rapids*. Waterfalls occur where the water drops a considerable height from one ledge to the next. Where number of waterfalls occur in succession they are known as *cascades*. Rapids are developed when water rushes through deep and often narrow gorges. The rate of river erosion is partly determined by the nature of the rocks over which it flows. Hard rocks will be excavated to a much smaller extent than soft ones. One of the best examples is afforded by the falls of Niagara in North America. The bed of the river is formed by the hard Niagara limestone which overlies the softer shales and sandstones. The water, as it rushes over the fall, dashes against the underlying soft rocks and wears them away at a greater rate, thus undermining the limestone

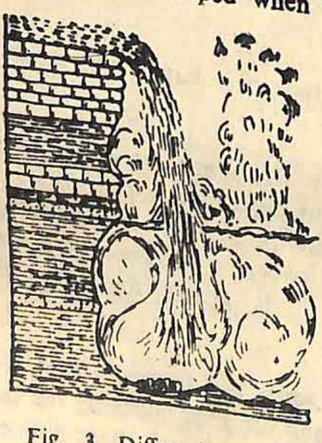


Fig. 3. Differential erosion.

which eventually by its own weight falls into the rapids below and is washed away.

Monadnock is an isolated hill or mass of rock which stands above the surrounding country. It is formed due to the erosion of surrounding rocks which are less resistant than the former. This is named after mount Monadnock in U.S.A. which was formed in this way.



Fig. 4

Mesa is a flat table-like mountain with steep slopes on at least three sides. This is formed from a plateau in an arid region and is due to occurrence of hard top layers of rocks which resist denudation.

Butte is similar to mesa, but smaller in size.

Hog back is a long narrow ridge in which both dip slope and scarp slope are great owing to the steep inclination of the beds.

Cuesta is a ridge formed on gently dipping rock strata from the more durable layers, which resist denudation better than the weaker layers.

Bad Lands: In arid regions areas with scanty vegetation are affected by occasional torrential rain and dissected into deep gulleys. Such areas gullied and bared by rain are almost valueless either for agriculture or pasture and are known as bad lands.

Pot-holes : Hollows known as pot-holes may be worn in hard rock of a river bed by the motion of pebbles which are swirled round by eddies, especially in the neighbourhood of waterfalls.

River capture : It sometimes happens that a river when it is cutting back vigorously in an easily eroded formation may approach

the course of a neighbouring stream and meet and divert the head waters of the latter into its own channel. This process is known as river capture or river piracy.

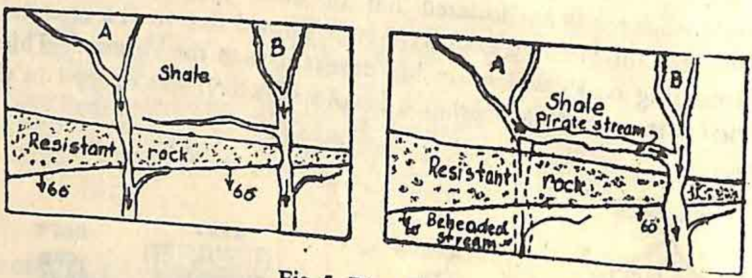


Fig. 5. River piracy.

Meanders : When a river has cut down nearly to base level it flows more slowly and begins to swing from side to side of its valley and the course of the river develops a series of big looped curves called meanders. If a river in the meandering stage breaks through the neck of the land at the end of one of the loops and thus shortens its course, it will leave a crescent-shaped lake called an ox-bow lake in the abandoned meander.

River Terraces : They are platform like land masses formed along the sides of a river valley. They are formed as a result of rejuvenation of a river flowing along its flood plains when it cuts a new channel in its own deposits. The new valley formed in that way is widened in course of time and a second flood plain is formed within the first one. By subsequent rejuvenation and formation of new channels the valley is bordered by a series of such river terraces each corresponding to a phase of rejuvenation and valley incision. River terraces are also formed due to a landslide or at end of a glacial epoch. The presence of river terrace is significant to an engineer as it helps in locating highways and rail-roads between two cities or regions. Moreover river terraces contain sand and gravel useful for the construction.

Confluence : In the middle or plains course of a river, it is joined by other streams called tributaries. The place where two such rivers join one another is called confluence.

Antecedent Rivers or Drainage : During the long life of a river, it may happen that an upwarping of the land may take place across its course. If the river has a gradient which will give it the

requisite energy and is cutting sufficiently fast, it may be able to saw down its channel through the upwarp in measure as it rises and thus maintain its course. A stream whose course has been thus determined by a previous topography and does not now conform to the present relief of the land is called antecedent river or drainage e.g., Himalayan rivers.

GLACIERS

Glaciers like rivers and wind wear away the surface over which they move and produce characteristic land forms. Ice is formed by the compaction of snow in cold regions and at high altitude, where mean annual temperature is near the freezing point of water and much of the snow remains unmelted. Snow as it falls, get compacted and acquires a granular texture and such granular snow is called *neve*. When snow accumulates to a great thickness, it will begin to move down a slope, and such a moving mass of ice is called a glacier. Glaciers are of three types.

(*i*) *Valley glaciers* (rivers of ice) are fairly common in mountainous areas of the world, e.g., Himalayas and Alps;

(*ii*) The *Piedmont glacier* (lake of ice), formed by the meeting of several valley glaciers on low ground at the foot of mountain range, and essentially a stagnant accumulation of ice, e.g., the Malaspina glacier, Alaska;

(*iii*) The *continental glacier* or ice caps (sea of ice) covering a large land area e.g., the ice-sheets of Greenland. Islands of rock standing up through ice sheet are called *nunataks*. Where the ice breaks away from the parent snow field, a big crevasse is formed and that is known as the *bergschrund*.

A glacier as it moves over the ground, behaves like a very viscous body, flowing over the irregularities of its course. It carries along boulders and stones of all sizes which fall on its surface from the valley walls on either side and superficial debris of this kind is called *moraine*. It frequently lies in two bands known as lateral moraines, parallel to the sides of the glacier. The confluence of two glaciers, as when a tributary enters the main valley results in the formation of a medial moraine.

Rock debris which falls into crevasses is carried forward within the ice as blocks. When ice melts, these blocks of rock masses are transported and left stranded wherever they happen to be and they are called indicator boulders or erratics.

Glacial Erosion: Glacial ice moving over a land surface acts as a soft abrasive and removes soil and loose material exposing the bed rock below. This surface debris, together with material which has worked its way down through the ice, is held in the lower part of the glacier and it is rubbed over the rock floor, which becomes smoothed in the process and lubricated by the melting of the ice under pressure; thus a glaciated surface is formed.

At the head of a valley occupied by a glacier, the plucking action of the ice at bergschrund forms an arm-chair shaped hollow called *cirque* which is sometimes occupied by a lake.

Rock obstructions in the path of a glacier are smoothed on their iceward slopes and "plucked" on the leeward side. When exposed to view after the removal of ice, they show the rounded forms known as *roches mountonnees*(named after its resemblance to backs of flock of sheep), which are typical of glaciated mountain regions. The profile of a glaciated valley presents a broad U-shaped form in cross section. In glaciated regions, it is found that the ice has eroded the main valley deeper than the tributary valleys and the latter are left cut off at some height above the new floor. They are known as *hanging valleys*. When streams flow along these valleys they form waterfalls.

Sediments transported and deposited due to action of glaciers are quite characteristic and they are known as *drift*. The deposit known as *boulder clay* is formed underneath the ice. It is more or less stiff clay composed of the ground up debris, boulders and stony fragments of all sizes.

A *drumlin* is a smooth oval-shaped mound generally less than 100 ft. in height. It is built of boulder clay or englacial debris and sometimes moulded over a *roches mountonnee*.

From the view point of an engineer boulder clay is one of the most difficult and treacherous deposits as it creates problems while

carrying out constructions. It is variable in character. It may be sandy or may contain many stones and boulders or pockets consisting mainly of gravel with a clay matrix or it may be almost without stones. Occurrence of hidden large boulders hinder the use of mechanical appliances and may have to be broken by blasting and the frequent variation in the deposit adds uncertainty to the work.

LAKES

Lakes occur as natural reservoirs contained in basin-like portions of the earth's surface. They vary in size from small ponds to great inland seas thousands of square miles in magnitude.

Lakes are formed due to various geological processes which may produce depressions upon the land surface. The following are the various types :

1. Due to crustal movements like folding and faulting large basins are produced which form lakes. They are known as *tectonic lakes*, e.g., the Tibetan lakes.

2. In some regions, damming of a river or a stream by glacial debris or alluvial deposits results in the formation of lakes. They are known as *dammed lakes*, e.g., the Himalayan lakes and the Dal lake in Kashmir.

3. When a river in its plains course, cuts off a meander, it will leave a crescent-shaped lake called an *ox-bow lake* in the abandoned channel.

4. Depressions produced by the dissolution of limestone serve as lake basins. They are called *solution lakes*, e.g., the Kumaon lakes.

5. *Volcanic lakes*, as their name implies, occupy the craters of extinct volcanoes, e.g., the Lonar lake in the Deccan Trap formations of Maharashtra.

6. In arid regions lakes are formed in depressions between sand hills or dunes formed due to wind action, e.g., the Sambar lake in Rajasthan and Dhands in Sind. Because of their richness in salt content they are described as *salt lakes*.

7. In coastal regions, due to formation of spits and bars along the shores, lakes and lagoons are formed, e.g., Lagoons of the

Malabar Coast, the pulicat lake near Nellore and the chilka lake in Ganjam

The uses of lakes are many and varied. They tend to check floods and so indirectly help to prevent great loss of life and material damage. Lakes supply water for irrigation. In many countries natural and artificial lakes are used as reservoirs. Fisheries of lakes are of considerable economic importance. Salt lakes become dry during summer months and supply salts. If lakes are of considerable size they increase the rainfall and moderate the temperature of surrounding areas.

OCEAN

Ocean is a great body of water which occupies the depressed basin—like portions of earth's surface. The partially separated water areas are known by different names. Thus there are the Atlantic Ocean,the Pacific Ocean, the Indian Ocean etc.

Functions of Ocean : The ocean supplies moisture to the atmosphere. It absorbs heat slowly and gives it up slowly and therefore acts as a great regulator of climate. It also supplies food for millions of people (fish and salt) and serves as a great highway of commerce.

Ocean basin: The depth of the ocean is determined by sounding. The unit of measurement is a fathom (6 feet) and the instrument employed in making the measurements is the *fathometer*. It measures the time required for a sound to travel to the ocean bottom and the echo to return to the boat. Based on the velocity of sound waves in water the instrument automatically registers the depth as the ship steams along its course.

The ocean has an average depth of about 2½ miles. The greatest known depth lies in the western part of the Pacific Ocean, 30,000 feet and on the eastern part of the Phillippine islands, 35,433 feet. The shallow portion of the ocean adjacent to the land is known as the continental shelf. It slopes gradually from the shore to about 100 fathom line where the bottom begins to descend more abruptly into abysmal depths.

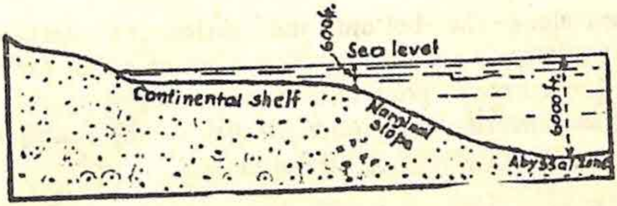


Fig. 6.

Sea Level : The surface of the ocean is the datum of reference plane for all topographic and geologic work. All level surfaces are theoretically parallel to mean sea level and that surface is assumed to be constant.

Composition of Ocean Water : Sea water carries in solution great quantities of mineral matter and thus it differs greatly from ordinary land waters. Mineral matter is constantly being removed from sea water by marine organisms that use it in forming the shells which are chiefly composed of calcium salts. Precipitation and evaporation remove mineral matter. During the periods of dessication due to evaporation, thick deposits of salt and gypsum are formed but probably are confined to shallow bays, coastal lagoons and closed basins. Common salt (sodium chloride) is accumulating in the ocean more rapidly than the calcium salts because it is rejected bv organisms in the making of skeletons or shells.

Temperature : The temperature of the ocean is dependent almost entirely on solar radiation and it varies greatly from equator to poles and from surface to abyssal depths.

Movements : Water is constantly in motion in the restless sea as the slightest disturbance in any part of the ocean gets transmitted through water to distant parts. One of the common causes is the drag or friction of the wind blowing along the surface. During heavy storms these movements are destructive, e.g., on the 5th October 1864 violent storm changed the level of sea at Calcutta by about 24 feet and inundated a large area.

Waves and Ocean Currents Waves are generated by winds and other agents and their motion is oscillatory The water returning

towards sea along the bottom and under the next incoming wave is known as the *undertow*. When waves strike the shoreline obliquely two currents result one at right angles to the coastline producing the undertow and other parallel to the coastline producing the long shore current or littoral current.

Tides : The periodic rise and fall of the sea is the tide. It is produced by the differential attraction of the sun and the moon on the earth. This attraction is effective on both land and sea but the sea is more mobile and therefore yields more readily to the pull thus exerted.

Coast Erosion : Movements in sea water may produce pronounced effects on coastal rocks owing to the mass of moving water and its velocity. The waves beating upon the coast incessantly result in wearing away of the coast. This is accomplished largely by grinding. The vertical cliff thus produced is known as *sea cliff*. That portion of land over which the sea has advanced by cutting of the cliff is called the *wave-cut terrace* while the continuation of this surface towards sea, produced by the deposition of materials resulting from the destruction of the cliff is called the *wave built terrace*.

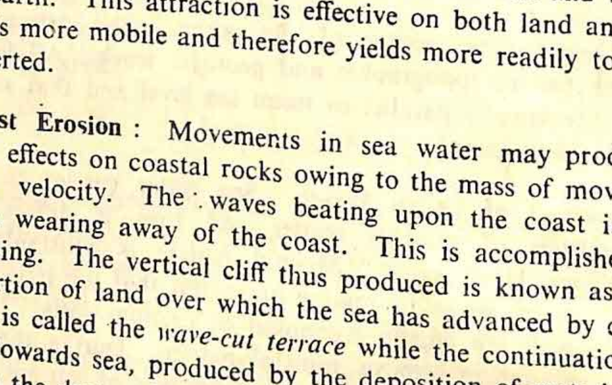


Fig. 7.

Shoreline Characteristics : Features of deposition along a shore may be built of both the material eroded by waves and material contributed by rivers to the sea. The transportation of the material is effected largely by currents set up along the shore by waves. A ridge built above sea level is known as the *barrier* or *offshore-ban*. A ridge which becomes a land projection is known as *spit*. When a spit is built almost or entirely across the entrance to the bay it becomes a *bar*. Islands become connected with the main land with the bars acting as the lines of connection when they are termed *tambolos*.

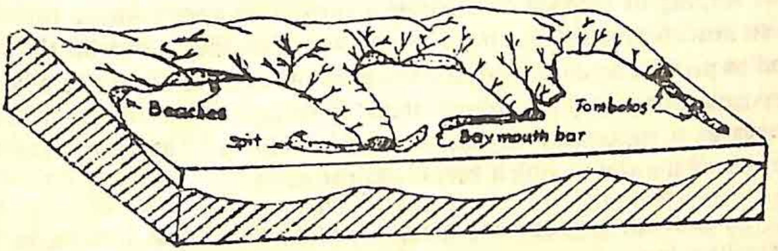


Fig. 8.

Coast Protection: Commercial traffic between nations having coast lines demand existence and maintenance of good harbours and the preservation of shore line. The harbour is sometimes closed up or shallowed either by sedimentation or by the gradual abrasion of land or both, when natural forces are allowed to operate and disturb. Hence for maintenance of good harbours an engineer must familiarise himself with the manner in which these natural forces operate and prepare to prevent them. Improvements of harbours are done by dredging (i.e., excavating material) and by construction of works like jetties, groynes and breakwaters for the protection of shore lines from shorecurrents.

Erosive action may be arrested locally by building of defences, such as, sea walls and groynes. Sea walls are constructed to protect a coast from wave action, the shock of which is taken by walls instead of by the coastal rocks. The form of construction may be a low bank of earth, sand or other material. On account of its relatively low cost a bank of this kind is often used for protecting agricultural land.

Timber stakes driven into the beach fronts have been used to break the force of the waves. Walls of concrete or stone are more durable but more costly and they are usually employed in the case of sea-side resorts generally in conjunction with a system of groynes. Many massive sea walls of this kind were built with a ertical or nearly vertical face. The breaking of waves against such a wall, however, may sometimes induce scour in front of the toe, leading to instability of structure if the scour is sufficiently deep. An alternative form of wall which has been employed in some places is one of the reinforced concrete, having a stepped or gently sloping seaward face.

The sloping or stepped face forms a protective apron whose function is to absorb most of the force of the waves as they move up the wall and to prevent scour. Groynes are used to retain or accumulate beach deposits along a shore where there is littoral drift. A good beach serves as a protection against erosion of the land as it absorbs the impact of the waves which break against it.

In general, groynes are placed normal to a coast line or to the prevailing long shore current and at a distance apart approximately equal to their length. There is much difference of opinion as to their dimensions and spacing, and conditions vary at each locality. Groynes are commonly made of timber but may be of stone work or concrete. They should be founded sufficiently deep to provide against scour at low tides.

ORGANIC LIFE—ITS GROWTH IN MODIFYING EARTH'S SURFACE

Many of the organisms which live in the sea build up their shells or hard parts with calcium or silica extracted from sea water. These hard parts form the limestones and siliceous deposits after the decay of the organisms. It is largely through living organisms and their ability to precipitate calcium carbonate and amorphous silica that the cementing material for other sediments are obtained. Therefore, the rock-building life of the sea is an important geologic factor.

The common lime and silica secreting forms of life belong chiefly to lower plants such as the bacteria, the diatoms and the algae and to the invertebrates among the animals. It seldom happens that bacterial remains are long preserved in recognisable condition in the deposits formed by their accumulation. Limestones found in the old geological formations, now wholly devoid of fossils may owe their origin to these organisms.

The lime secreting animal life of the sea includes almost every group from their lowest group (foraminifera) to the highest division of the invertebrates. The prolific limestone builders occur among the foraminifera and corals (the hydrozoa, the anthozoa, the crinoidea etc.).

Amongst sea organisms, corals play a dominant role as reef-builders. Corals reproduce by budding in plant-like fashion and

they live in colonies. As the colonies expand and grow upwards the older organisms decay and their skeletons constitute the limestone deposits which form wall-like structures called reefs. A reef is a belt along which the corals live, their skeleton building up a platform on which the colony flourishes. Coral reefs are of common occurrence in the warm, shallow waters of the tropical and sub-tropical oceans especially in the Pacific Ocean. Modern reef building corals are confined to clear waters with a temperature that does not fall below 68°F and a depth that varies from a little below mean sea level to about 150 ft. The most suitable place for the growth of a reef is towards open sea, where waves bring food, oxygen and the necessary calcium for the skeletons.

Massive reefs built along the shore are called *fringing reefs.* Those that are separated from the shore by a channel or lagoon are known as *barrier reefs.* Those that surrounded lagoons and more or less circular in shape are known as *atolls.* According to Darwin the fringing reef which grows chiefly towards sea, is changed to a barrier reef separated from mainland by a lagoon as the island sinks; and then as the island sinks further and is submerged below sea level the corals continue to build up the fringing reef and it becomes an atoll.

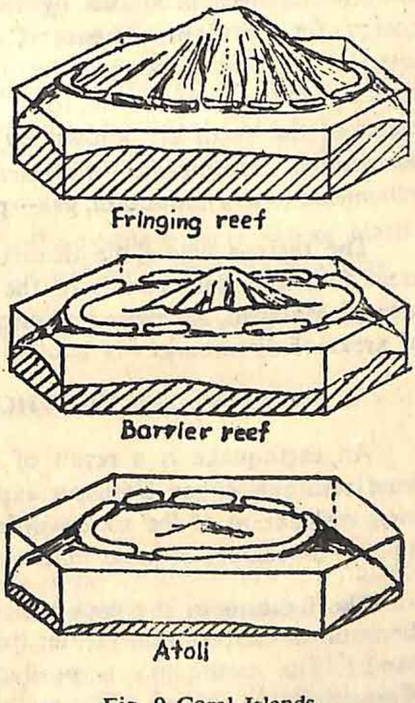


Fig. 9. Coral Islands.

Atolls of Laccadive and Maldive Islands in the Indian Ocean are built up of recent corals. Corals seen near Andaman and Nicobar Islands form massive rocks. Reefs made entirely of skeletons of the coral organisms are sometimes very extensive. As for example, the

Great Barriers Reef of Australia which has a length of 1200 miles along the north eastern coast.

DIASTROPHISM

So far we have studied about the work of the external agencies such as wind, water and heat of the sun in shaping the outer shell of the earth. Though the processes of weathering and erosion are very slow and **continuous** ones, the changes produced by them in course of ages are stupendous and marked. It is these processes which are partly responsible for the greater dynamic movements such as mountain building, subsidence and elevation of land regions to restore isostatic equilibrium, e.g., the Himalayas and the Gangetic plains.

The dynamic movements such as earthquakes, volcanic eruptions, mountain building etc. are sudden and violent in character and the changes produced by them are marked. The controlling energy for these movements is derived chiefly from the earth's interior as heat produced by the disintegration of radioactive elements and as gravitational force of the earth. These greater movements of the earth are known by different names such as *orogenic movements*, *epeirogenic movements*, *diastrophism* and *tectonic movements* (*oros*—mountain, *gen*—producing and *epeiros*—mainland).

The regions where the disturbances are common, lie along the great fold mountain chains of the world like Alps, Himalayas and around Malayan, Japanese and circum-pacific regions. This great line of areas of disturbances is known as *orogenic belt*.

EARTHQUAKES

An earthquake is a result of sudden disturbance in the earth's crust resulting either from an explosive volcanic eruption or from some dislocation of the rock within a few miles of the surface, often slipping movement of great masses like faults.

The fracture in the rock which causes a tectonic earthquake is the result of elastic strain greater than the strength, the rock can withstand. The earthquake is produced by the relative displacement of neighbouring portion of the earth's crust. Local geological features have a marked effect on the results of earthquake shock, i.e., the

earthquakes cause more damages in the areas of unconsolidated materials than in those with solid rocks exposed at the surface.

Rossi-forel Scale of Intensities of Earthquake Shocks

1. *Microseismic shock*—recorded by a single seismograph or by seismograph of the same model but not by several seismograph's of different kinds; felt by an experienced observer.

2. *Extremely feeble shock*—recorded by several seismographs of different kinds; felt by a small number of persons at rest.

3. *Very feeble shock*—felt by several persons at rest; strong enough for the direction or duration to be recorded.

4. *Feeble shock*—felt by persons in motion; disturbance of the movable objects, doors, windows, cracking of ceilings.

5. *Shock of moderate intensity*—felt generally by everyone, disturbance of furniture, beds, etc., ringing of some bells.

6. *Fairly strong shock*—general awakening of those asleep; general ringing of bells, oscillation of chandeliers, stoping of clocks, visible swinging of trees and shrubs; some startled persons leave their dwellings.

7. *Strong shock*—overthrow of movable objects, fall of plaster, ringing of church bells; general panic without damage to buildings.

8. *Very strong shock*—fall of chimneys, cracks in the walls of buildings

9. *Extremely strong shock*—partial or total destruction of some buildings.

10. *Shock of extreme intensity*—great disaster; ruins; disturbance of the strata, fissures in the ground; rocks fall from mountains.

Slight disturbances are called *earth tremors*. The earthquakes are violent earth tremors. The earthquake is propagated outwards from the place of disturbance called the focus or *seismic centre* in every direction. A portion on the surface of the earth which is vertically above the place of the origin or seismic centre is called the *epicentre* or *epifocus*.

The instrument used for recording the vibration of earth crust is known as *seismograph*. The vibrations are recorded on a strip of paper and the diagram produced is known as *seismogram*. In principle, the seismographs are quite simple. A seismograph is essentially a pendulum with a long period. A much simplified diagram of one is shown here. A heavy weight P is suspended by a spring from a rigid frame E firmly fastened to the earth often by means of pillar of concrete resting directly on bed rock. On a platform of this frame is a revolving drum D. A stylus S attached to the weight rests against a sheet of paper wound around the drum. When an earthquake occurs the frame E including the drum will oscillate a bit while the mass P because of its great inertia will momentarily remain at rest. Thus a wavy line will be traced on the paper recording the passage of the earth wave. In ordinary operation as long as no disturbance is passing through the instrument the record consists of a straight line. Seismographs used in modern times are much more refined and complicated than this.

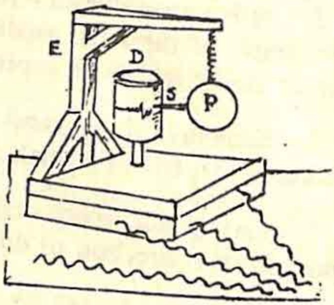


Fig. 10. Seismograph.

When an earthquake occurs, the wave sent out from the centre of the disturbance pass through the machine and the lines recorded become wavy with varying amplitude. Here is shown a sample of

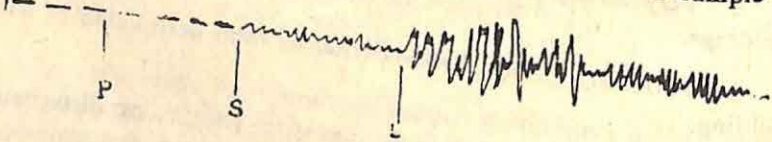


Fig. 11. Seismogram.

such a record from an earthquake centre situated at a great distance from the observatory. The letters P, S and L indicated below the curved line mark the appearance of the three wave trains that make up the usual record. The first is called a primary wave because it travels fastest and arrives first. The second is called a secondary

wave and the third a long wave. It is noted that these waves are separated from each other on the seismogram by time intervals which increase as the distance from the disturbance to the observatory increases. Thus at an observatory a few hundred miles from the earthquake the times of arrival of waves may differ by only a few minutes whereas from more distant earthquakes they are separated by greater intervals.

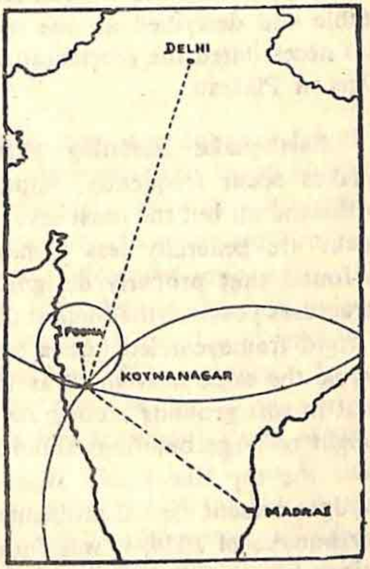


Fig. 12.

The epicentre of an earthquake can be fixed by the study of the interval between 'S' and 'P' waves of the three recordings received from three different observatories as illustrated in the figure 12.

The major earthquake regions of the world are the circum Pacific region and along the Alpine-Himalayan mountain system. These are generally zones of large gravitational anomalies in the crust of the earth. The majority of Indian earthquakes occurred along the Himalayan mountain belt.

The important Indian earthquakes are as follows :—

Delhi	1720
Calcutta	1737
Kashmir	1885
Assam	1897
Kangra Himalayas	1905
North Bihar	1934
Assam	1950, 1952

All these areas are in the zone of weakness and strain implied by severe crumpling of the rock beds in the elevation of Himalayas. The earthquake shocks experienced in the peninsula are generally quite feeble. Occasionally such shocks are felt in some parts of

the peninsula particularly around its margin. The reason may be that the faults along the western coast have not yet attained completely equilibrium. The severe earthquake that occurred in Koynanagar on 11th Dec. '67 is described to be something strange and quite new in the Deccan region which is considered to be highly stable and described as one of the shield areas of the world. This has necessitated the reorientation of the ideas of the stability of the Deccan Plateau.

Earthquake Resisting Structures. In countries where earthquakes occur frequently, important buildings are now designed to withstand all but the most severe shocks. Structures founded on hard rocks are generally less damaged than those on soft ground. It is found that properly designed steel framed or reinforced concrete structures possess the highest degree of immunity from damage. Thus a rigid frame carried on a strong foundation would undergo as a whole the same movement as the ground. Hence it is recommended that in soft grounds a concrete raft foundation should be used. The height of large buildings should not exceed 100 feet and heavy loads near the top like heavy **stonework** in copings should be avoided. Bridges present special problems in seismic regions. During the Bihar earthquake of 1934, it was found that bridges with screw pile foundations had stood up best to the shock while brick arches were easily broken and girder bridges supported on stonework piers also failed. In house construction light roofs and chimneys are recommended. Bricks poorly bonded and laid in dry mortar failed while walls laid in cement with wet bricks stood the test better. Reinforced concrete houses have proved relatively stable. The most secure house is one that will move as a unit. It is important also to use fireproof building materials in seismic regions, since fires are a common result of earthquake damage

Based on the information regarding the seismicity of the regions furnished by seismologists, the engineers design structures in such a way that they can withstand destructive power of the earthquake. The School of Earthquake Research and Training, at Roorkee in India is carrying out this work. Buildings can be designed to stand large earthquakes. The cost will be much. The main aim of the Institute is to design buildings in such a way that they can minimise loss of life during earthquake and keep costs down.

Study of seismic records has revealed important facts about the structure of the earth's interior. Principles of seismology are successfully applied to locate hidden structural features that are important in the search for petroleum and ore deposits and also in site investigations.

VOLCANOES

Volcanism includes all phenomena that are connected with molten rock matter and its movements. Interior of the earth is very hot and at some places the heat is sufficiently great to melt the solid rocks. Due to the compressive stresses of diastrophism heat is generated. This heat may also be due to radioactive processes, with the result that bodies of earth material fuse, despite the pressure to which they are subjected. Once the material is in a liquid state its density is decreased and it tends to rise towards the surface. As it rises, it continuously enters regions of less pressure, and consequently the heat it carries with it may be sufficient to liquefy some of the rocks it passes through thus adding to its volume. All the liquid mass may not reach the surface. The greater part of the volcanism is a subterranean phenomenon. When the molten matter solidifies before it reaches the earth surface, it forms an intrusive rock. If it is poured out upon the surface it is extrusive.

A volcano is a opening in the earth's surface through which hot rocks are thrown out. The rocks may be expelled in a fluid state as lavas or as solid rock fragments. Nearly always steam and other gases are ejected with the rocks and lavas. If solid matter or lavas accumulate around the opening they build up a cone which increases in size and becomes a hill or mountain.

The volcanoes best known to us are more or less conical hills with craters at the top from which regularly or occasionally clouds of steam or other gases are ejected. There are many kinds of volcanoes. Some only give rise to a single eruption and are not known to break out again (Monte Nuvo near Naples); some erupt violently and do enormous damage but only at long intervals (Vesuvius, Etna and Krakatoa); others have frequent and regular eruption of much milder type (Stromboli). The active volcanoes are distributed in belts, some of which are extended parallel to the

borders of the continents and the almost complete ring round the Pacific Ocean is known as the "pacific ring of fire". Volcanoes are much less abundant around the Atlantic.

Dormant volcanoes are those which have had no eruptions during historic times, but still show fairly fresh signs of activity and have obviously been active in geologically recent times. Other volcanoes which are formerly active are declining in activity, some of them emitting only steam and other gases. *Geysers* are hot springs from which water is expelled vigorously at intervals. They are characteristic of some regions of declining volcanic activity and are situated in Iceland, the Yellowstone Park in U.S.A. and in New Zealand.

In contrast to the central type of eruption there are eruptions of great lava flows quietly pouring out from fissures developed on the surface of the earth. No explosive outburst accompany these eruptions. They are known as fissure eruptions, e.g., Deccan Trap formations in India.

MOUNTAINS

The word mountain is a term applied to all elevated land regions that rise to considerable heights above their surroundings. Mountains are formed in different ways and the chief agents which cause their formations are volcanism, differential erosion and crustal movements.

Volcanic mountains are formed due to the accumulation of lava and other volcanic products into heaps of mountainous size e.g., Kilimanjaro in Africa, Vesuvius in Europe and Kotapaxi in South America.

Erosional mountains are formed due to weathering and erosion from a featureless plateau. They are not mountains in the true sense of the word as they are nothing but the remnants of the original plateau, which escaped erosion. Hence, they are known as *relict mountains* e.g., Western Ghats and Eastern Ghats in Peninsular India.

Fold Mountains are formed as a result of crustal movements. The great mountains of the world like Alps, Himalayas were formed

due to such movements. These mountains came into existence due to upheaval of a great sea basin and they are chiefly made of thick strata of sedimentary rocks. As evidence of their origin we find in them the fossils, the remains of dead organisms which lived in sea during the period of sedimentation.

The origin of these fold mountains can be explained thus. First the sediments were deposited in a large sea basin known as *geosyncline*. During this process, the pressure of accumulated sediments on the oceanic floor increased and caused rupture, resulting in sliding in of the adjacent parts of the continental masses. The sediments which were laid in horizontal layers thus got folded due to lateral pressure exerted by the continental masses. The broken parts of the oceanic floor sank into basaltic substratum and

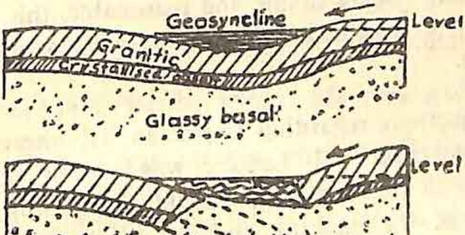


Fig. 13. Formation of fold mountains.

got liquefied due to heat in the interior of the earth. This produced change in the volume and as a consequence the folded rocks got uplifted as high lands above the sea.

ORIGIN OF THE EARTH

Since very early times man has pondered over the question of the origin of the earth and amongst the many theories put forward, three of them are important.

Nebular hypothesis :—This was proposed by the German philosopher, Kant and by the French Mathematician, Laplace. According to this hypothesis, the earth originated along with other planets from a gaseous nebula whose diameter was considerably larger than the

present diameter of Pluto's orbit. Laplace postulated a rotational movement for this nebula and as a result of this, it was then a cooling and shrinking nebula. As its speed of rotation increased and shrinking continued, it bulged at the equator. Finally a ring of nebular material was left behind when centrifugal force just exceeded the inward gravitational pull. This process of the ring formation was repeated again and again until ten rings had been left behind one for each of the nine planets and one for the planetoids

Each of the successive rings collapsed, but while the planets thus formed were still gaseous, they too developed rings out of which satellites were formed in precisely the same way as their parents had originated before. The planetoids resulted from the disruption of one of the rings into many bodies instead of a single one and the sun is the residual portion of the extraordinarily shrunken nebula. Being simple and reasonable, this theory remained the most widely accepted one of the earth's origin for nearly a century (1796).

Many objections regarding Laplacian hypothesis were raised at the turn of the century. If Laplace was correct, the sun should be ready to give off another ring, should be rotating rapidly, should bulge greatly at the equator and should practically possess all the rotational momentum of the solar system. Unfortunately, none of these phenomena has been observed. According to the ordinary behaviour of gases it is very doubtful whether the gaseous material leaving nebula would ever have formed rings that could break up into planets. Moreover this hypothesis fails to explain the differences in densities of planets.

Cloud dust theory :—This was proposed by Carl Von Weizsacker, a German Astronomer. According to this theory the various planetary bodies would have evolved due to aggregation of fine dust particles originally scattered through the entire region now occupied by the planetary system.

Planetesimal hypothesis :—The two Americans, **Chamberlin** and Moulton, respectively a geologist and an astronomer suggested a radically new mode of origin for solar system. According to their theory, a passing star could have caused a partial disruption of the sun. When the disturbing star approached the sun tidal bulges were developed on

the opposite sides of the sun such as tidal bulges are heaped up in our oceans by the moon's attraction. But according to Chamberlin and Moulton the explosive forces in the sun also aided in its tidal disruption. The sun has two great unstable belts which encircle it on either side of the solar equator. In these two great belts the solar prominences are clearly seen at present. Imagining that these belts were also in existence some billions of years ago, as the disturbing star approached the sun two gaseous jets or bolts were shot out from the sun's nearest eruptive belt. Ten bolts in all were erupted from the sun in rapid succession and pulled into orbits around the sun as the star receded. The five great tides on the side of the sun towards the star have developed into five larger, lighter and more distinct bodies (major planets) while the tides on the opposite side of the sun developed into five inner, denser and smaller planets (minor planets).

Major planets. Neptune, Uranus, Saturn, Jupiter and Pluto.

Minor planets. Mars, Earth, Venus, Mercury and Planetoids.

Although each bolt was gaseous when it left the sun it soon condensed and formed into liquid and solid particles called planetesimals. The mid portion of the swarm of the particles formed the nucleus of the planet. The planets have been built up to their present sizes by the slow accretion of solid planetesimals to the original nuclei. Some of the meteorites which blaze our skies to-day are planetesimals which the earth is only now picking up. Satellites were formed as secondary nuclei like planets by addition of planetesimals. Since the planets were formed by the accumulation of planetesimals this theory is known as *planetesimal hypothesis.* Though this hypothesis offers an explanation for the distribution and spacing of large and small planets, yet in this theory also many defects have been pointed out. The main objection to this hypothesis is found in the density stratification of the earth which seems to be the natural result of the cooling of a once molten globe.

Tidal theory :—Two English physicists, Jeffreys and Jeans offered a new theory known as *tidal theory* which is only a modification of the planetesimal hypothesis. Due to the close approach of the passing star, tidal forces were produced which were sufficient enough to cause separation of matter from the sun, and from the star as well.

No matter was ejected from the opposite side of the sun; the matter between the sun and star was pulled out as the star receded into an elongated ribbon, the shape being thickest in the middle and tapering towards each end (something like a cigar). Such a ribbon would be unstable and would break up into separate masses which the star's attraction would set in motion around the sun. These masses, at first, fluid and very hot, would have cooled to form the present planets.

The evidence for this theory is quite good. In the first place the cigar-shaped filament, thickest in the middle, corresponds pretty well with observed sizes of the planets. For, if we imagine the planets lying in a straight line from the sun, in the order of their distances, the largest planets, Jupiter and Saturn, occur about the middle of this line. In either direction from the middle, towards or away from the sun, the planets tail off in size approximately, at any rate. They would fit fairly well into a cigar-shaped filament.

It may be concluded thus that on one point and one only do the various theories agree, viz., that the earth's origin is bound up with the origin of the solar system and the materials which make up our small planet should be the same except for minor variation in amount, as that of other planets and their satellites.

AGE OF THE EARTH

The record of the long history of the world expressible, not in thousands of years, but in millions, is written just as page after page, layer after layer of the stratified rocks and the story disclosed by their study is one of the successive changes of life and scene of the most impressive kind brought by long continued process, and not merely by sudden and violent catastrophies.

Several methods are available for estimating the age of the earth and they are all based on one common principle. The rate at which some process is going on at present is measured as accurately as possible and the average change produced in one year is compared with the total effect produced by that process during the interval that has elapsed since its commencement. The two processes denudation and deposition and accumulation of salt in seas, suggest ages of about 300,000,000 years. Unfortunately, whatever process is considered, the deposition of sediments or the accumulation of salt, there

remains the difficulty that its rate has not been uniform throughout. Supposing these calculations produced reliable results, still the solutions would be incomplete, for the earth must have existed before the oceans occupied their basins and mountains originated.

Lord Kelvin tried to solve the problem by calculating the time that had elapsed since the earth's surface was too hot for the condensation of the oceans or for the habitation of living beings. He estimated that more than 40 million years could have escaped since the molten earth solidified. After the discovery of the element radium, its properties and its presence in rocks, the idea that the earth was only a cooling body, was abandoned. It was then concluded that the age of the earth must be more than that estimated by Kelvin.

Lead Uranium method :—Uranium is a radioactive element which disintegrates at a constant and measurable rate. It gives off helium atoms and leaves lead behind. It is estimated that 1 gm. of uranium will yield 1/7400 million gm. of lead in one year. By measuring the amount of uranium and lead in a specimen of uranium-bearing rock, scientists can calculate the ratio of the two and get the number of years ago that the uranium was formed in pure state. Uranium is contained in certain kinds of rocks of which pitchblende is the most important. The oldest rock so far tested was uraninite from Russia, estimated to be 1,800,000,000 years old. Thorium also disintegrates and similar calculation may be made from its disintegration.

Astronomical methods. Inferences are drawn from the shape of the orbits of various planets and satellites. The orbits do not change at uniform rates but their changes are determined by known laws so that the mathematicians can calculate the rates at which changes occurred under past conditions and hence by totalling up, can deduce the time needed to establish the present conditions.

Jeffreys gives the age as 10,000 million years from the orbit of mercury and about 4000 million years from the orbit of moon.

Tidal retardation of earth's rotation. The rotation of the earth is not absolutely uniform and the day is becoming longer by about one second in 120,000 years. The change affects observed times of

ancient eclipses to a measurable extent. The explanation depends on the tides produced by the sun and moon. A reaction on the moon makes it go farther off and explains how it can have receded to its present distance from its probable original close proximity to the earth's surface. An estimate of the time needed to bring the moon to its present distance indicates an age of order of 4,000,000,000 years.

All the theories seem to be necessary as it is very difficult to stick to one exclusively and it may be concluded thus that the age of earth is probably more than 2000 million years.

INTERIOR OF THE EARTH

Our knowledge about the interior of the earth is mostly based on observations made on the surface. From observations in wells, mines and borings, we come to know that there is downward increase in temperature and pressure. The average density of the earth determined by precise physical methods is 5.52. Rocks found on the surface of the earth have an average density of 2.7 which is less than half the value for the entire earth. Therefore the interior of the earth must consist of materials much heavier than the rocks with which we are familiar.

It is probable that all planets and planetoids of the solar system have essentially the same composition. The wandering fragments of planetary matter, known as meteorites which the earth sweeps up as it revolves in its orbit, are of particular interest in this connection. The commonest known meteorites are composed of iron and nickel. Accordingly, it is inferred that the central core is composed of Ni and Fe with an average density of about 8.

Study of earthquake waves has furnished the most reliable information about the earth's interior. The earthquake vibrations recorded by seismographs at varying distances from an earthquake centre, reveal significant differences in the elastic behaviour of the materials through which they travel.

All known evidences indicate convincingly that the earth has a density stratification with the heaviest material near the centre and the lightest near the surface. It is considered from this arrangement that the earth passed through a molten stage during the early part of

its history and gravity caused most of the heavy metal to settle towards the centre and progressively lighter substances formed spherical shells between the core and surface. According to this view the earth is conceived as the result of a gigantic metallurgical operation analogous to a smelter furnace. In a smelter furnace, when a large mass of ore is smelted, the metal settles to the bottom of the container, while directly above it, is formed a layer of sulphide and oxide over which floats at the top the lighter materials, slag made of the molten rock.

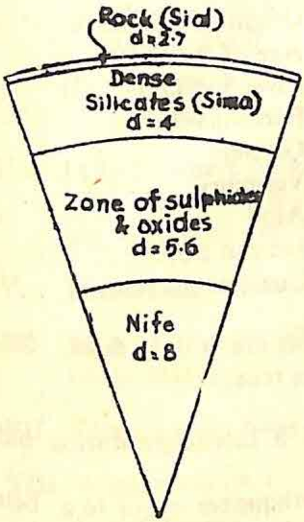


Fig. 14. Earth shells.

From the above it is inferred that the shell 1200 miles thick, extending from a depth of 600 miles to the metallic core is composed of metallic sulphides and oxides with an average density of 5.6. This inferred composition affords satisfactory explanation to the decline in the rate of increase of the earthquake velocities below the 600 miles level. The evidence from earthquakes indicates that there is a zone of dense silicates extending from the zone of metallic sulphides and oxides to the surface with an average density of 4. The outermost shell which is a few tens of miles thick is composed of rocks; basalt and gabbro types occurring at the bottom with granitic rocks overlying them with an average density of 2.7.

It should be remembered that the entire conception is an hypothesis, no part of which is subject to direct proof at present and it is based entirely on the observations made at the surface.

QUESTIONS

Group-A

I. Match the word or phrase in the left column with the correct word in the right column.

1. Fissure Eruption	*a.* Eastern Ghats
2. Volcanic Mountains	*b.* Sial

3. Coral reef — c. Mountain building movements
4. Isostasy — d. Origin of the Earth
5. Lead uranium method — e. Age of the Earth
6. Planetesimal hypothesis — f. River Erosion
7. Earth's Crust — g. Earthquakes
8. Cirque — h. Glaciers
9. Break-waters — i. Vesuvius
10. Pot holes — j. Atoll
11. Erosional Mountains — k. Deccan traps
12. Epicentre — l. Coast protection

II. Decide whether the following statements are true or false. Reword the false statements to make them true.

(1) A peneplain is characteristic of a landscape during old age stage in a river valley.
(2) Over 90 percent of the large earthquakes occur in a belt that surrounds the Atlantic ocean.
(3) Alps and Himalayas are good examples of relict mountains.
(4) Geysers are characteristic of some regions of declining volcanic activity.
(5) Our knowledge about the interior of earth is mostly based on observations made on the surface.
(6) A good beach serves as a protection against the erosion of the land as it absorbs the impact of the waves which break against it.
(7) Study of seismic records has revealed the structure of the earth's interior.
(8) The profile of a glaciated valley presents a broad, V-shaped form in cross section.
(9) Some of the materials which blaze our skies to day are satellites which the earth is picking up only now.
(10) The tidal theory propounded by two English Physicists, Jeffreys and Jeans is only a modification of the Nebular hypothesis.

Group-B

I. What is meant by weathering? Describe its effects on rocks and their constituents.

II. Write an essay on 'River as a Geological Agent'.

III. (*a*) Commercial traffic between nations having coast lines demand existence and maintenance of good harbours and the preservation of shorelines—Comment.

(*b*) Discuss briefly the various methods adopted in coastal protection.

IV. In India where do earthquakes occur frequently and why? Describe the methods adopted in the design of buildings, bridges etc., in seismic regions.

V. Discuss the various theories that explain the origin of the earth.

VI. Give an account of the more important views regarding the age of the earth.

VII. Write a short essay on the nature of the interior of the earth.

VIII. Write notes on :

1. Exfoliation 2. River piracy 3. Differential Erosion 4. Run off 5. Barchans 6. Roches mountonnees 7. Atoll 8. Spit and bar 9. Seismogram and Seismograph 10. River terraces.

IX. Give a detailed account of the following :

(*a*) Formation of soils
(*b*) Reclamation of desert lands
(*c*) Coral Islands

X. Distinguish between the following groups of features :

(*a*) a young and mature valley,
(*b*) a glaciated and river valley,
(*c*) a submerged and emerged coast line.

CHAPTER III

MINERALOGY

A mineral is naturally occurring homogeneous inorganic substance having distinctive physical properties and a more or less definite chemical composition. Coal and petroleum, though of organic origin are also included among minerals. Almost all minerals are solids, the only exceptions being mercury, water and mineral oil (petroleum).

Minerals are to a large extent the units which make up the rocks of the earth's crust or the outer shell. Many of them are useful to man. A knowledge of minerals is obviously necessary to the geologist and to some extent to the engineer, the chemist and the metallurgist.

Most of the minerals are identified by their physical properties and external form (*Morphology*). For identification of some minerals, especially the ores, certain chemical tests are also necessary. One must, therefore, have a knowledge of all the three kinds of properties of minerals—physical, morphological and chemical. The classification of minerals is primarily a chemical one. Many minerals have a definite chemical composition. For all minerals it is definite within certain limits.

The great majority of minerals when produced under favourable conditions, assume the geometric forms called *crystals* and these forms are characteristic as in the case of plants and animals. An elementary knowledge of *crystallography* is essential in the study of minerals.

Microscopic examination of mineral slides is necessary for the correct recognition of non-metallic minerals as the optical properties are also important in the description and determination of minerals. This method has a great advantage over chemical methods in that, a very small quantity of material suffices and two or more substances may be recognised in the presence of one another.

After the properties of a mineral are ascertained and the mineral determined, there yet remains the facts of its occurrence and associa-

tion and the problem of its origin. The occurrence of certain minerals in certain rocks and mineral deposits is characteristic and the mineral associations are more or less typical.

In this chapter, the study of minerals is treated under the following heads:—(1) *Crystallography* and (2) *Descriptive Mineralogy*.

CRYSTALLOGRAPHY

The great majority of minerals when the conditions of formation are favourable, occur in definite and characteristic geometric forms known as crystals. The word crystal has been derived from the Greek word *krystallos* meaning clear ice. Quartz is one of the minerals that usually occur in forms having characteristic shape, being bounded by flat faces. From the transparency of this mineral and the occurrence in it of included material it was thought by the ancient Greeks that quartz resulted from the freezing of water under intense cold and hence the name *krystallos*. In course of time by a natural extension of the term *krystallos* came to signify any mineral showing such geometric forms.

The study of crystals is called crystallography. Crystals are bodies bounded by surfaces usually flat, arranged on a definite plan which is an expression of an orderly internal arrangement of the atoms. Minerals occur as crystals and they are formed by the solidification from the gaseous or liquid states or from solutions—a process known as crystallisation.

When a mineral exhibits definite molecular structure even though it may not have external crystalline form, it is described to be *crystalline*. The crystalline structure of some minerals appears indistinctly even under the microscope and it is called *cryptocrystalline*. The term *amorphous* is applied to those minerals in which definite molecular structure is entirely wanting.

Symmetry: All crystals show by the arrangement of their faces a definite symmetry which enables one to group them into different classes. The degree of symmetry varies in different minerals and it is defined with reference to three criteria of symmetry. (1) Plane of symmetry, (2) Axis of symmetry and (3) Centre of symmetry.

Plane of Symmetry: A plane of symmetry divides a crystal into two similar and similarly placed halves. In other words, such a plane divides the crystal so that one half is the mirror image of the other. Planes of symmetry can be illustrated by considering a cube. A cube has nine planes each of which divides it into two halves so that one half is the reflection of the other. The traces of these nine planes are indicated on the faces of the cube in the figure 16.

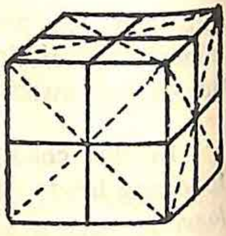


Fig. 15.

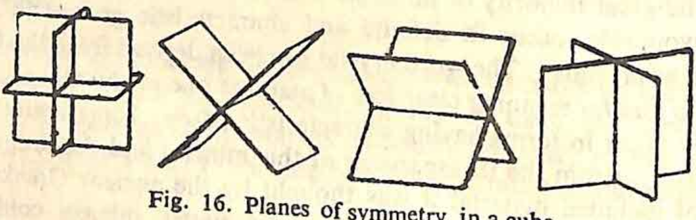


Fig. 16. Planes of symmetry in a cube.

Axis of Symmetry: If a crystal, on being rotated, comes to occupy the same position in space more than once in a complete turn, the axis about which the rotation has taken place is called axis of symmetry. Depending upon the degree of symmetry, a crystal may come to occupy the same position two, three, four or six times in a complete rotation. The terms applied to these different classes of axes are as follows :—

Two times	—	Two fold or diagonal
Three times	—	Three fold or trigonal
Four times	—	Four fold or tetragonal
Six times	—	Six fold or hexagonal

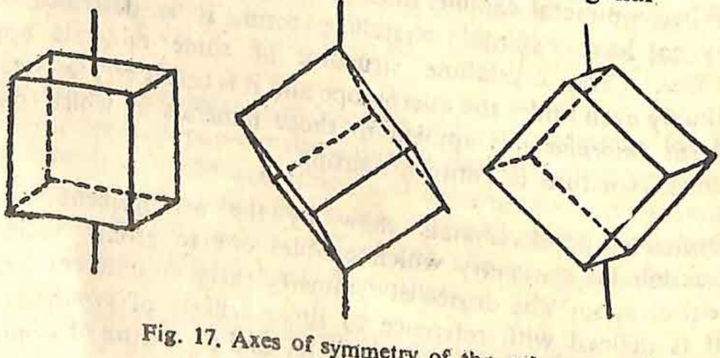


Fig. 17. Axes of symmetry of the cube.

Centre of Symmetry. A crystal is said to have centre of symmetry if an imaginary line can be passed from any point on its surface through its centre and a similar point can be found on the line at an equal distance beyond the centre.

Classes of Symmetry. Different combinations of the various symmetry elements just described give rise to thirty-two distinct crystal classes (from theoretical considertions, it has been shown that these comprise all possible symmetry classes of crystals). These thirty-two classes may be grouped further into six systems, the classes of each system having certain close relations to one another. Of the thirty-two possible crystal classes the majority are of little interest to the mineralogist, since practically all known mineral species can be placed in one of ten or twelve classes. In the table given on the page 41 and figure19 are listed the crystal systems with mineral examples.

Crystallographic Notation. In the description of a crystal especially in regard to the position of its faces it is found convenient to assume certain lines passing through the centre of the ideal crystal as a basis of reference. These lines are called the *crystallographic axes*. Their directions are to a greater or lesser extent fixed by the symmetry of a crystal. Each one of the six systems has got several classes differing among themselves in their symmetry. One of these classes is convenienty called the *normal class* since it is common and exhibits the highest degree of symmetry possible for the given system while the other classes are lower in degree of symmetry.

Crystal form. In cubic or isometric system the various crystal forms have individual names viz., Cube, Octahedron, Hexoctahedron etc. In other systems, the forms are referred to as, *Base, Prism, Pyramid, Dome*, etc. and they usually occur in combination. *Base* is that form which meets only the vertical axis and parallel to other axes. Prisms are those which meets the two horizontal axes and parallel to the vertical axis. Pyramid is one which meets all the three crystallographic axes. In orthorhombic monoclinic and triclinic systems where all the three axes are unequal, a face inclined to all three axes is known as a pyramid. A face which cuts any one of the three axes and parallel to the other two is termed as a *pinacoid*; if the face is cutting 'a' axis. that is called a-pinacoid or macro pinacoid in orthorhombic

system in which 'a' axis is called brachy axis and 'b' axis as macro axis. The pinacoids and domes are designated as brachy and macru after the axis to which they are parallel. A dome is one which cuts one lateral or horizontal axis and vertical axis, and parallel to the other horizontal axis. If the horizontal axis, which is parallel to a dome is a-axis or brachy axis, that is called brachy dome in orthorhombic system. A orthorhombic crystal of olivine is illustrated for example with its various faces indicated in the figure 18 below :—

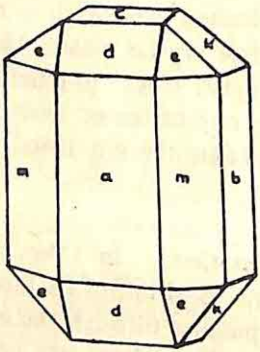


Fig. 18. Olivine Crystal.

a=Macropinacoid **b=Brachypinacoid**
c=Basal pinacoid **m=Prism**
d=Macrodome **k=Brachydome** **e=Pyramid**

In the description of faces and in the determination of their position and angular inclination certain lengths of these axes are assumed as units. The *parameters* of a plane consist of a series of numbers which express the relative intercepts of that plane upon the crystallographic axes. They are expressed in terms of the established unit lengths of these axes. Simplified and abbreviated expressions derived from the parameters are commonly used and these are known as the *indices*, *Miller's indices* being the most common.

TABLE OF CRYSTAL SYSTEMS

System	Axes	Mineral Examples
Cubic (or) Isometric	3 equal axes at right angles to one another	Garnet, leucite flourspar, rock-salt, pyrite, magnetite
Tetragonal	3 axes at right angles; two equal and horizontal, one vertical axis longer or shorter than the others	Zircon, cassiterite idocrase
Hexagonal	4 axes; three equal and horizontal, and spaced at equal intervals, one vertical axis	Quartz, nepheline, apatite, calcite, tourmaline, beryl
Ortho-rhombic	3 axes at right angles, all unequal	Olivine, enstatite, barytes, topaz, sulphur
Monoclinic	3 unequal axes; the vertical axis (c) and one horizontal axis (b) at right angles, the third axis (a) inclined in the plane normal to (b).	Orthoclase, micas hornblende, augite gypsum
Triclinic	3 unequal axes, no two at right angles	Plagioclase felspars, axinite, kyanite

X-ray study of crystals has established the general law that the ratio between the intercepts on the axes for the different faces on a crystal can always be expressed by rational numbers as 1 : 2, 2 : 3, 1 : ∞ etc. and never 1 : $\sqrt{2}$ etc. Hence the Miller's symbols must always be either whole numbers or zero.

Stereographic Projection: The stereographic projection is one of the methods to exhibit the symmetry of any one of the crystal classes readily by illustration. The axis of binary, trigonal, tetragonal and

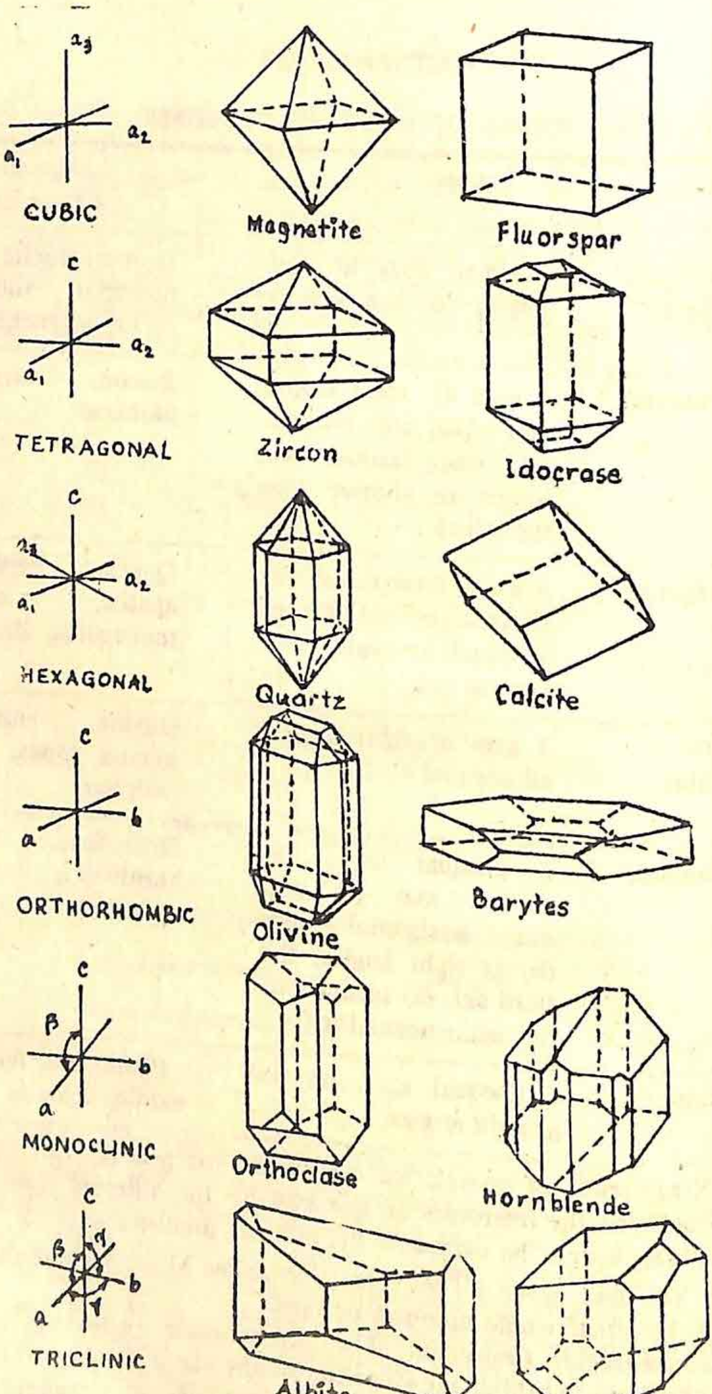
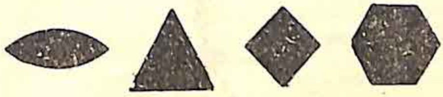


Fig. 19. Crystal systems

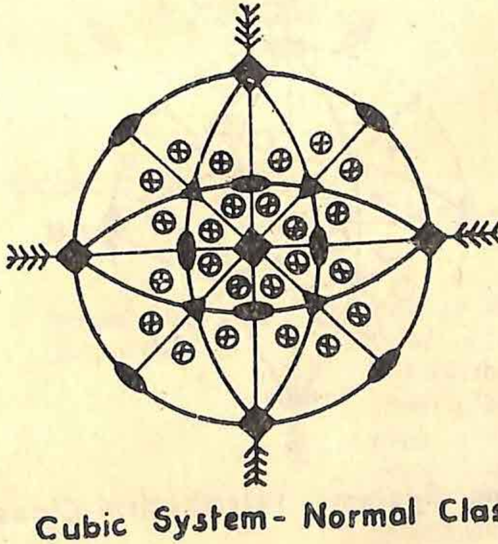
hexagonal symmetry are shown respectively by the following signs :



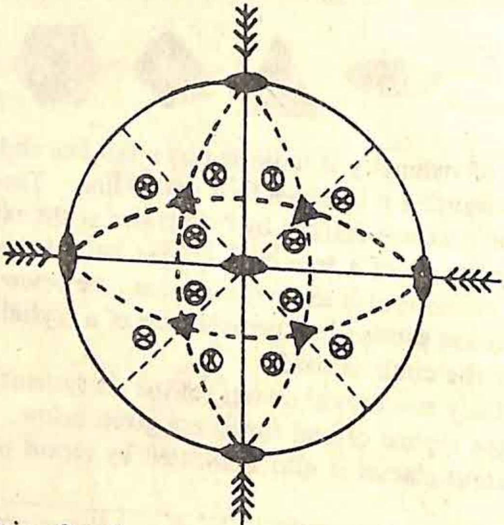
A plane of symmetry is indicated by a full line and if the plane of symmetry is wanting it is shown by a dotted line. The position of the crystallographic axes is marked by the arrows at the extremities of the lines. The presence of a face in the upper half of the crystal (above the plane of projection) is shown by a cross, one below by a circle. If both the faces are present in a vertical zone of a crystal, double sign a cross with in the circle is used.

Of the thirty two crystal classes (of the six systems) the important classes and the typical crystal forms are given below. The symmetry of the important classes is also illustrated by means of stereographic projection.

System	*Class*	*Forms present*
Isometric System	Normal Class (Galena type)	Cube, Octahedron Dodecahedron, Tetrahexahedron, Trisoctahedron, Trapezohedron, Hexoctahedron

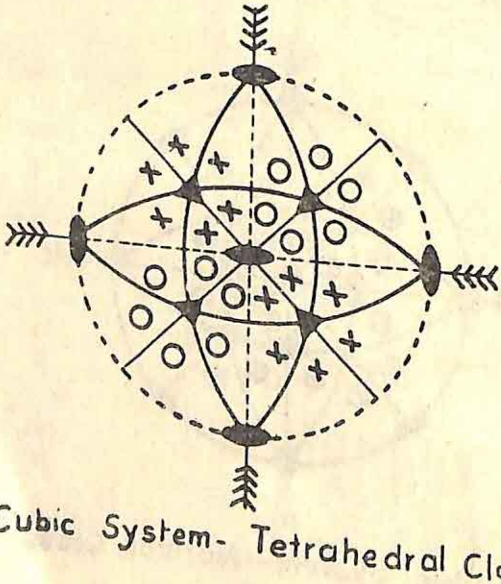


Cubic System- Normal Class



Cubic System - Pyritohedral Class

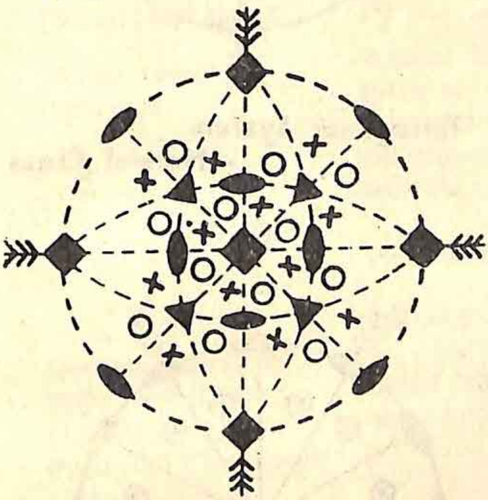
Fig. 21.



Cubic System- Tetrahedral Class

Fig. 22

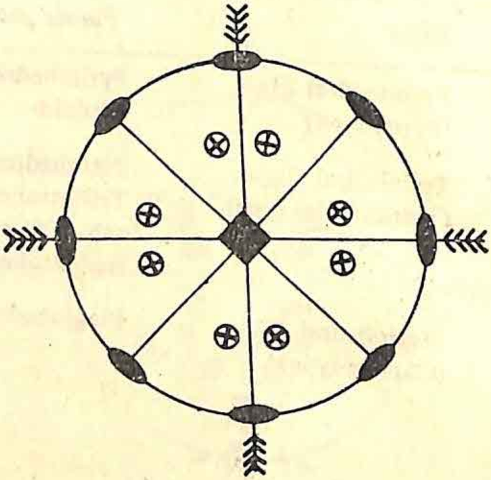
System	Class	Forms present
	Pyritohedral Class (Pyrite type)	Pyritohedron Diploid
	Tetrahedral Class (Tetrahedrite type)	Tetrahedron, tetragonal—Tristetrahedron, Trigonal—Tristetrahedron, Hextetrahedron
	Plagiohedral Class (Cuprite type)	Plagiohedron



Cubic System
- Plagiohedral Class

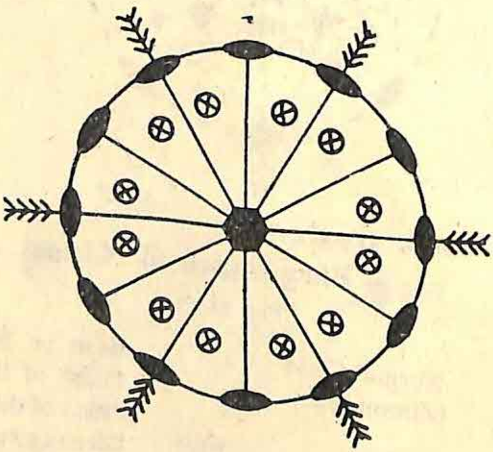
Fig. 23.

System	Class	Forms present
Tetragonal System	Normal Class (Zircon type)	Base or Basal pinacoid Prism of the First order Prism of the Second order Ditetragonal Prism Pyramid of the First order Pyramid of the Second order Ditetragonal Pyramid



Tetragonal System
- Normal Class

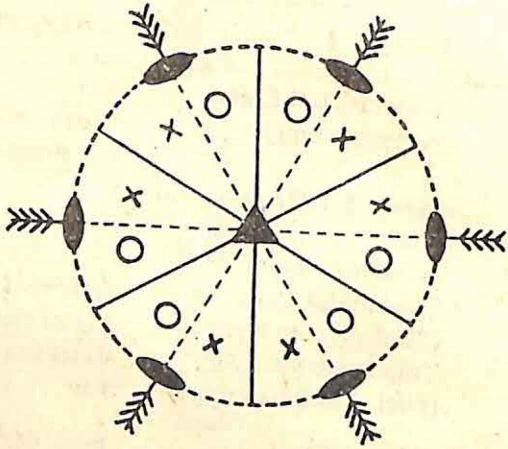
Fig. 24.



Hexagonal System
- Normal Class

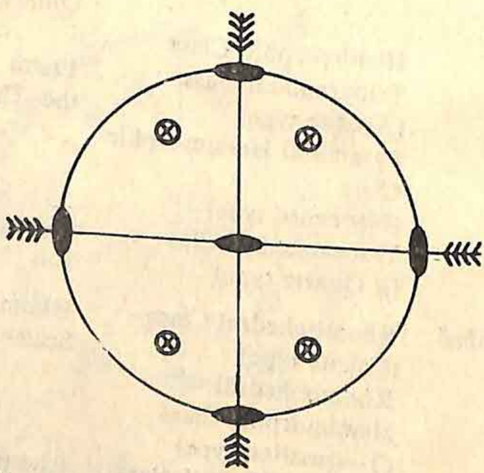
Fig. 25.

System	Class	Forms present
	Tripyramidal Class (Scheelite type)	Prism and Pyramid of the third order
	Pyramidal Hemimorphic Class (Wulfenite type)	... ...
	Sphenoidal Class (Chalcopyrite type)	Sphenoid, Tetragonal Scalenohedron
	Trapezohedral Class (Nickel Sulphate type)	Tetragonal trapezohedron
Hexagonal System	Normal Class Beryl type	Base or Basal pinacoid Prism of the First order Prism of the Second order Dihexagonal Prism Pyramid of the First order Pyramid of the Second order Dihexagonal Pyramid
	Hemimorphic Class	... ...
	Tripyramidal class (Apatite type)	Prism and pyramid of the Third order
	Pyramidal Hemimorphic Class (Nephelite type)	... ...
	Trapezohedral Class (β Quartz type)	Hexagonal Trapezohedron
Rhombohedral Division	Rhombohedral Class (Calcite type)	Rhombohedron Scalenohedron
	Rhombohedral Hemimorphic Class (Tourmaline type)	... ...
	Trirhombohedral class (Phenacite type)	Rhombohedron of the Third order
	Trapezohedral Class (α Quartz type)	Trigonal Trapezohedron



Hexagonal System
– Rhombohedral Class

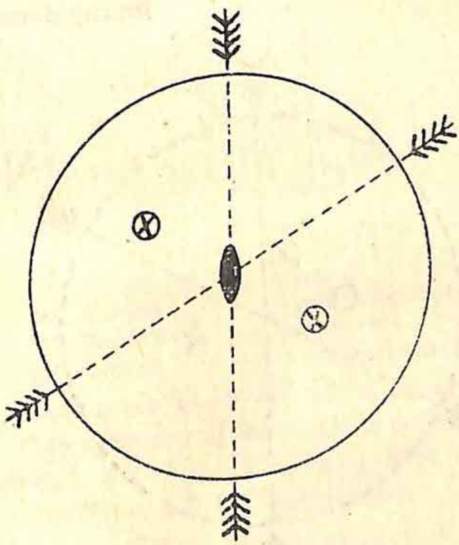
Fig. 26.



Orthorhombic System - Normal Class

Fig. 27.

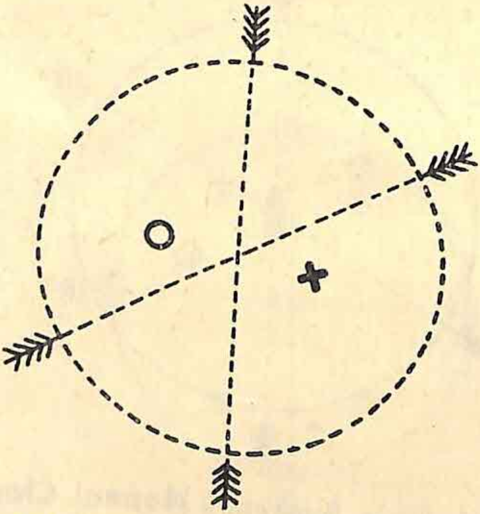
System	*Class*	*Forms Present*
Orthorhombic System	Normal Class (Barite type)	Base or C. Pinacoid Macropinacoid or *a*. Pinacoid Brachy pinacoid or *b*. pinacoid Prisms Macrodomes Brachydomes Pyramids
	Hemimorphic Class (Calamine type)	... ...
	Sphenoidal class (Epsomite type)	Sphenoid



Monoclinic System - Normal Class

Fig. 28.

System	*Class*	*Forms Present*
Monoclinic System	Normal Class (Gypsum type)	Base or *c*. Pinacoid Orthopinacoid or *a*. pinacoid Clino pinacoid or *b*. pinacoid Prisms Orthodome Clino dome Pyramids
Triclinic System	Normal Class (Axinite type)	Base or *c*. pinacoid Macropinacoid or *a*. pinacoid Brachy pinacoid or *b*. pinacoid Prisms, Macrodomes, Brachy domes, Pyramids.

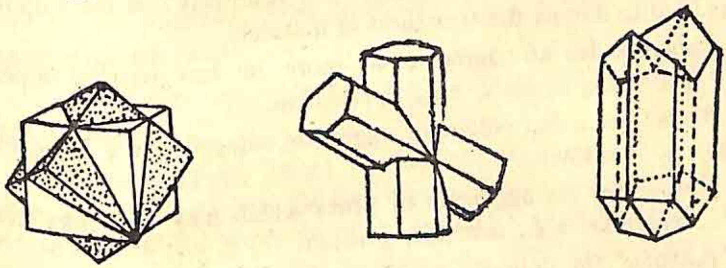


Triclinic System - Normal Class

Fig. 29.

Compound or Twin Crystals: Crystals commonly occur in groups and the individuals composing any group may have various relations to each other. In the majority of cases these relations are irregular and depend upon the accidental conditions of growth. In other cases the relations of the individual crystals to each other are definite and conform to some law. If all faces, edges etc., of one individual are parallel to the similar elements of a second individual, the two are said to exhibit parallel growth or grouping. When, however, two individuals grow together with only a part of their similar faces, edges etc., in parallel positions they are said to form a twin crystal or group.

Twin crystals may be defined as the intergrowth of two or more individuals. They consist of two or more portions consisting of the same substance, that are joined together in such a way that some crystallographic direction or plane is common to the parts of the twin. In twin crystals, one part is in reverse position to the other part, or the second half of the twin may be conceived as produced



[a] [b] [c]

Fig. 30. Twin crystals.

[a] Fluorite — penetration twin
[b] Staurolite — cross twin
[c] Gypsum — swallow tail twin

by the rotation about some line of one half of the crystal through an angle of 180°. They often appear externally to consist of two or more crystals symmetrically united and sometimes have the form of a cross or star. Examples are shown in figure 30.

DESCRIPTIVE MINERALOGY

PHYSICAL PROPERTIES

Included under this head are colour, lustre, structure, hardness, cleavage, fracture, specific gravity, tenacity, odour and taste.

Colour: It is very useful in identifying minerals in spite of the fact that colour is not constant in most of the minerals and commonly the colour is due to stain or impurities in the mineral. The *streak* which is the colour of the powder is more nearly constant than the colour. The streak is determined by marking unglazed porcelain or simply by scratching it with a knife and observing the colour of the powder.

Lustre: It is the appearance of a fresh surface of a mineral in ordinary reflected light. It may be

metallic as in galena and pyrite,
Glassy or *vitreous* as in quartz,
resinous or *greasy* as in opal,
pearly as in talc, and
silky as in fibrous minerals such as asbestos.

Structure: This is a term used to denote the shape and form (state of aggregation) of minerals. The following are the important terms used to denote the structures of minerals.

Columnar for an aggregate of more or less parallel imperfect prismatic crystals, e.g., tourmaline.

Bladed for a flat columnar aggregate, shaped like a knife blade, e.g., kyanite.

Fibrous for an aggregate of fibres which may or may not be separable, e.g., asbestos, gypsum.

Radiated for columns or fibres diverging trom central points, e.g. celestite.

Lamellar for a platy aggregate i.e., the mineral made up of separable plates, e.g., chlorite.

Foliated for the ability of a mineral to separate easily into thin plates, e.g., mica.

Micaceous for an aggregate of mineral which can be split readily into exceedingly thin sheet, e.g., hematite.

Granular for an aggregate of crystalline particles of about the same size, e.g., dolomite.

Oolitic for an aggregate of small spheres (like fish-roe), e.g., siliceous oolite.

Pisolitic for an aggregate of larger spheres (shot-like), e.g., bauxite.

Botryoidal for an aggregate like bunch of grapes, e.g., psilomelane.

Mammillary for an aggregate composed of low rounded prominences, e.g., chalcedony.

Reniform for kidney shaped aggregate, e.g., hematite.

Stalactitic for a cylindrical or conical (icicle-like) form of minerals generally due to deposition by dripping water, e.g., calcite.

Nodular (or Concretionary) for irregular, rounded or ellipsoidal lumps of minerals, e.g., azurite.

Earthy for a uniform aggregate of exceedingly minute particles like those of China clay, e.g., magnesite.

Dendritic for tree-like or moss-like form usually produced by deposition of minerals from solutions by capillary action, e.g., manganese oxide (wad).

Coralloidal for minerals exhibiting the forms of corals, the marine organisms.

Pseudomorph (False form). Minerals when crystallise assume definite and characteristic forms. Occasionally some minerals are found to exhibit the form of other mineral species and yet differ from them entirely in chemical composition. Such forms are known as pseudomorphs. These are formed by coating of one mineral on the crystals of another, filling up of cavities by a different mineral matter, substitution of new particles for the original particles or by gradual chemical change, e.g., limonite after pyrite

Hardness: It is the resistance a mineral offers to abrasion or scratching and is measured relative to a standard scale of ten minerals known as Moh's scale of hardness.

MOH'S SCALE OF HARDNESS

1. Talc
2. Gypsum
3. Calcite
4. Fluorspar
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond

Cleavage: It is the tendency of many crystallised minerals to break or split in certain parallel directions yielding more or less smooth surfaces known as cleavage planes. Some crystals like mica, have perfect cleavage. Others like quartz and garnet have none. Cleavage may be *perfect* (good or distinct) and *imperfect* (poor or indistinct) according to the ease of splitting and the smoothness of planes obtained. Cleavage is defined as *basal, prismatic, rhombohedral, cubic, pyramidal octohedral* and *dodocahedral* according to the face to which the cleavage planes are parallel. A basal cleavage represents one direction, prismatic cleavage two directions, rhombohedral and cubic three directions, pyramidal and octohedral four directions and dodocahedral six directions of cleavage.

Parting is very similar to cleavage, but it is due to weakness produced by shearing after the formation of crystal. It is otherwise known as false cleavage, e.g., corundum.

Fracture: It is the appearance of the broken surface of the mineral. Minerals which have no cleavage are said to fracture rather to cleave. Further, the break of a cleavable crystal in any direction other than that of cleavage is also fracture. Fracture differs from cleavage in being more or less irregular uneven or curved and in no definite crystal direction. Fracture is described as:

conchoidal when the surfaces produced are smooth and curved often concave, like those of some shells, e.g., obsidian, flint;

uneven when the surface is rough and entirely irregular (this is the commonest type in mineral), e.g., quartz;

even when the surface, though rough with many small irregularities, is approximately a plane, e.g., limestone;

splintery when it breaks in minute threads or needle like forms, e.g., tremolite; and

hackly when it breaks with rough and sharp points. e.g., native copper.

Specific Gravity. Specific gravity of a mineral is the ratio of its weight to the weight of an equal volume of water. After some experience. an approximation to the specific gravity may be made by holding the mineral in the palm of the hand and throwing it slightly up. Accurate determination of the specific gravity can, however, be made by mechanical means using Jolly's spring balance in the case

of smaller fragments and Walker's steelyard balance in the case of larger specimens.

Jolly's Spring Balance: This consists of a spring suspended vertically against a graduated scale. To the lower end of the spring are attached two scale pans, one below the other, the lower scale pan being always immersed in water. The reading a of the bottom of the spring on the scale is taken. A small fragment of the mineral is placed on the upper pan and a second reading b taken. The specimen is then transferred to the lower pan, and a third reading c taken. Then b—a is proportional to the weight of the mineral in air and b—c to the loss of weight in water so that, specific

$$\text{gravity} = \frac{b-a}{b-c}.$$

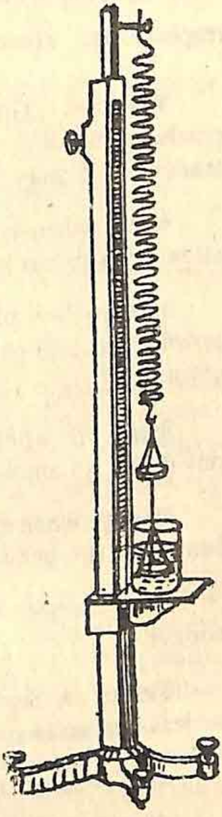


Fig. 31.
Jolly's spring balance.

Walker's Steelyard Balance: This consists of a long graduated beam which is pivoted near one end and counterbalanced by a heavy weight suspended from the short arm. The specimen is suspended and moved along the beam until the beam comes to the horizontal position which is observed by a mark on the upright shown on the right of the figure. The reading a is taken. The specimen is then immersed in water and moved along the beam till the latter comes to horizontal

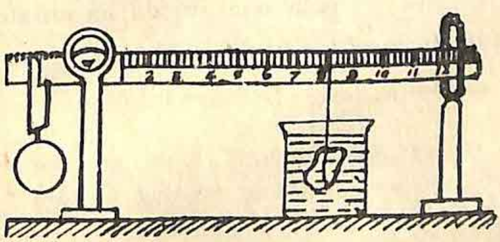


Fig. 32. Walker's steelyard balance.

position. The second reading b is taken. The readings a and b are inversely proportional to the weights of the body in air and water respectively. Hence Sp. Gr. $=\frac{1/a}{1/a-1/b}=\frac{b}{b-a}$

Tenacity: The resistance which the mineral offers to breaking, crushing, bending or tearing—in short its cohesiveness is known as tenacity. It may be

brittle when parts of a mineral separate in powder or grains on attempting to cut it, e.g., sulphur,

sectile when pieces may be cut off with a knife without falling to powder but still the mineral pulverises under hammer, e.g., graphite, gypsum,

malleable when slices may be cut off and these slices flattened out under a hammer, e.g., native gold, silver and copper.

flexible when the mineral will bend without breaking and remain bent after the bending force is removed, e.g., talc, selenite and

ductile when the mineral can be drawn into thin wires, e.g., copper.

Taste: A few minerals which are soluble in water have more or less characteristic taste which are described as follows :

Acid or sour—the taste of sulphuric acid.

Alkaline—the taste of soda or potash.

Astringent—the taste of vitriol.

Bitter—the taste of epsom salt.

Cooling—the taste of potassium or sodium nitrate.

Pungent—the taste of ammonium chloride.

Saline or salty—the taste of common salt.

Odour : In general minerals have no odour, but friction, moistening with breath, crushing, heating or attack by acids may cause odours which are described as follows:

Argillaceous the odour of moistened or heated clay.

Bituminous that of minerals containing bitumen such as asphalt.

Fetid that of rotten eggs.

Garlic or alliaceous that from arsenic, obtained by friction or heat from arsenopyrite.

Horse radish odour obtained by heating ores of selenium.

Sulphurous the odour of sulphur dioxide obtained by rubbing pyrite or heating many sulphides.

Fluorescence and Phosphorescence: Minerals which become luminescent during exposure to ultraviolet light, X-rays or Cathode rays are fluorescent. The continued emission of light by a substance (not incandescent) produced especially after heating, exposure to light or to an electrical discharge is called phosphorescence.

Fluorescence is shown by some fluorite, the mineral from which the property receives its name. The fluorescent colours of different minerals and different specimens of the same mineral vary greatly. Fluorescence is most commonly produced by excitation with ultraviolet light. This property is having an increasing commercial and industrial significance. Since most scheelite (tungsten ore) fluoresces prospecting for that mineral is frequently carried out at night with the aid of ultraviolet light.

Rock-forming minerals: Rocks are the units which compose the earth's crust or outer-shell of the earth and the minerals are the units which compose the rock masses. Though there are hundreds of minerals only a few of them are of common occurrence as rock forming minerals.

The estimates stated in the table given show approximately the minerals which compose the average igneous and sedimentary rocks. The metamorphic rocks are chemically similar to igneous and sedimentary rocks.

MINERAL COMPOSITION OF AVERAGE IGNEOUS AND SEDIMENTARY ROCKS (CLARK AND WASHINGTON)

Igneous Rocks		Sedimentary Rocks		
Minerals	Percent	Minerals	Shale percent	Sandstone percent
Quartz	12.0	Quartz	22.3	66.8
Felspars	59.5	Felspars	30.0	11.5
Pyroxenes and Amphiboles	16.8	Clay	25.0	6.6
Micas	3.8	Limonite	5.6	1.8
Other Minerals	7.9	Carbonates	5.7	11.1
		Other Minerals	11.4	2.2
Total	100.0		100.0	100.0

Felspars. These are the most abundant of all the silicate minerals. They make up about half the rocks of the earth's crust. They form monoclinic and triclinic crystals and are aluminous silicates of K., Na or Ca. The three common molecules being

Orthoclase	—	$KAlSi_3O_8$
Albite	—	$NaAlSi_3O_8$
Anorthite	—	$CaAlSi_2O_8$

Mixtures of albite and anorthite occur in all proportions and constitute the plagioclase felspars—albite, oligoclase, labradorite, bytownite, andesine, anorthite. Starting with albite Na content decreases and Ca increase to anorthite. They are generally light coloured and are characterised by two good cleavages. In orthoclase, these make angles of 90° hence the name (*orthos*-straight, *klao*-I break) Albite and anorthite have cleavages and make angles of about 86°, hence they are termed plagioclase. Orthoclase felspar is commonly pink or flesh coloured, albite is usually white and anorthite is commonly grey green.

This finds its use largely in ceramic industry. India has large resources of felspar for this purpose. Large quantities of this mineral are obtained from the dumps of mica mines. e.g., Mica belt of Nellore in the Andhra State and Hazaribagh in Bihar.

Felspathoids : These minerals form in the place of felspars in certain rocks rich in alkalies and deficient in silica. Unlike felspars, the felspathoids are relatively rare being restricted to special kinds of igneous rocks. The more abundant felspathoids are nepheline and leucite and less common are sodalite, noselite and hauynite.

Quartz : Composition–SiO_2. Next to felspars, this is the most abundantly occurring material of the earth's crust. It is colourless or white when pure but many coloured varieties occur the colour being due to traces of impurities. It has no cleavage and it breaks like glass. It occurs in all kinds of rocks, igneous, sedimentary and metamorphic. Veins of quartz are seen in the oldest crystalline rocks. It can be easily recognised as hard, glassy grains of irregular shape and without cleavage. It is harder than felspar, and cannot be scratched with a knife. Its hardness is 7.

Many varieties of quartz are recognised, the three main classes are as follows :

Pheno-crystalline—Rock-crystal, amethyst, rose quartz, milky quartz, cat's-eye, tiger-eye.

Cryptocrystalline Chalcedony, carnelian, agate, flint, jasper, chert.

Amorphous—Opal.

Many varieties of quartz are used in jewellery and for ornamental purposes. Agate and chalcedony are used in scientific instruments, chemical and radio apparatus. Sand is used for mortar, plaster and glass. Ground or crushed quartz and flint are used in wood filler, pottery, polishing-soaps and as an abrasive. Much crushed quartz is used as a flux in metallurgical work and in making refractory bricks. Some of the varieties like amethyst and opal are used as semi-precious stones.

Pyroxenes : The pyroxenes constitute an important group of minerals that are generally recognised by their stout crystals and their two good cleavages almost at right angles to each other. Most pyroxenes are dark coloured. They are Ca, Mg and Fe silicates in composition. The most important varieties are :—

Orthorhombic pyroxene	—	Hypersthene.
Monoclinic pyroxene	—	Augite.

Amphiboles : This group of minerals crystallises in the orthorhombic, monoclinic and triclinic systems, but only the monoclinic amphiboles are of importance. They have a tendency to form long, prismatic crystals and have two sets of cleavage, crossing at angles of 124 and 56°. The chief varieties are hornblende, tremolite and actinolite and their fibrous varieties known as asbestos. Amongst them hornblende is the most common variety.

Hornblende. Complex aluminous silicate of Ca, Mg, Fe and Na.

Tremolite and Actinolite. These are known as non-aluminous amphiboles These minerals occur mainly in metamorphic rocks.

Asbestos is the fibrous form of tremolite in which crystals are long and flexible. In commerce, the term asbestos also includes another serpentinous variety known as chrysotile. These minerals are useful because of their fibrous nature which enables them to be woven into fire-proof fabrics, cord and brake linings and made into sheets, boards, tiles and felt. The tremolite asbestos is available in India in Seraikala in Bihar, Mysore and Rajasthan.

Mica : All the minerals belonging to Mica group crystallise in monoclinic system. They are all characterised by their highly perfect basal cleavage, yielding very thin, tough and elastic laminae or flakes. A blow with a dull pointed instrument on a cleavage plate of mica develops in all the varieties a six-rayed percussion figure. In composition they are aluminous silicates of K, Mg and Fe. Mica deposits occur in the form of books of varying thickness in the oldest crystalline rocks known as pegmatites.

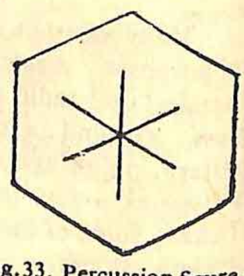


Fig.33. Percussion figure.

The important varieties of mica are :—

Muscovite	— White mica	— Potash mica.
Biotite	— Black mica	— Magnesium and iron mica.
Phlogopite	— Brown mica	— Magnesium mica.
Lepidolite	— Violet mica	— Lithium mica.

India is responsible for the three quarters of the world's production of sheet mica and of this probably 80% comes from the mica belt of Bihar and 20% from the Nellore district in the Andhra State. Being resistant to heat, it is used in furnace doors and as insulators in electrical apparatus and machinery. It is also powdered, mixed with oil and used as a lubricant.

Olivine : Composition—Iron magnesium silicate. It is found in many basic rocks and usually occurs in stout crystals. It is glassy like quartz but is generally olive green or yellow in colour. Its grain in a rock often resembles that of granulated sugar. Clear varieties are used as gemstones.

Garnet : Garnet is a widely distributed mineral occurring most commonly in metamorphic rocks. There are several kinds of garnet of which the most common one is a red variety known as almandine. The varieties are :—

Grossularite	— Calcium aluminium garnet.
Pyrope	— Magnesium aluminium garnet.
Almandine	— Iron aluminium garnet.
Spessartite	— Manganese aluminium garnet.
Andradite	— Iron calcium garnet.
Uvarovite	— Calcium chromium garnet.

Garnets crystallise in the cubic system and occur as rhomb dodecahedrons or trapezohedrons or as combinations of these

two forms. Many varieties are used as gemstones. Because of its high hardness it is used as an abrasive material. Large quantities of this mineral occur as coastal sands along the Coromandal Coast and Travancore

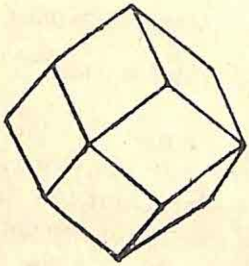


Fig. 34.
Dodecahedron.

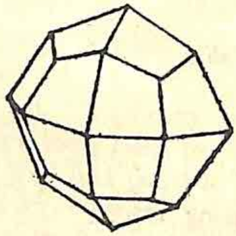


Fig. 35.
Trapezohedron.

The other common rock forming minerals are epidote, chlorite, limonite, calcite, magnetite, hematite and ilmenite.

The description of the physical properties and the chemical composition of all the minerals including the rock-forming minerals described above are given in the following pages.

(Also see Appendix)

DESCRIPTION OF MINERALS

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
SILICATES				
1. **Felspars.**				
Orthoclase	$KAlSi_3O_8$	Monoclinic	Tabular, massive or granular.	White, grey or flesh red
Microcline	$KAlSi_3O_8$	Triclinic	,,	grey, pink or green
Albite	$NaAlSi_3O_8$.	,,	Tabular, lamellar	White
Oligoclase	Na, Ca, Al silicate	,,	Tabular	White
Andesine	Na, Ca, Al silicate	,,	Granular	Grey to White
Labradorite	Ca, Na, Al silicate	,,	Cleavable masses	Grey to blue
Anorthite	$CaAl_2Si_2O_8$	,,	Granular	Light grey
2. **Felspathoids.**				
Leucite	$KAlSi_2O_6$	Pseudoiso-metric	As pheno-crysts in volcanic rocks	White to grey
Nepheline	$NaAlSiO_4$	Hexagonal	Granular	Colourless to white or yellow, grey, green or brownish red.

Lustre	Cleavage	Fracture	Hardness	Sp. Gr.	Remarks
Vitreous	Two at right angles	Uneven	6 to 6.5	2.5 to 2.6	Transparent variety, adularia is used as a gemstone under the name "moonstone".
,,	,,	,,	,,	,,	The green variety is known as "Amazon stone".
,,	Perfect at oblique angles.	,,	,,	,,	Transparent varieties used as gemstones under the name "moonstone".
,,	Less perfect	,,	,,	,,	—
,,	,,	,,	,,	,,	—
,,	,,	,,	,,	,,	Exhibits play of Colours.
,,	,,	,,	,,	,,	—
Vitreous to dull	Nil	Sub-conchoidal	5.5 to 6	2.5	Occurs as trapezohedral crystals. Transluscent.
Greasy	Present	Uneven	,,	2.5 to 2.7	

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Sodalite	Sodium, Aluminium silicate with Sodium chloride	Isometric	Massive	Blue
Lazurite	Sodium, Aluminium silicate with sulphur	Isometric	Compact massive	Azure blue
3. Pyroxenes.				
Enstatite	$MgSiO_3$	Ortho-rhombic	Massive, fibrous, lamellar	Yellow, green, grey or brown
Hypersthene	$FeMgSiO_3$	Ortho-rhombic	,,	,,
Diopside	Calcium, Magnesium silicate	Monoclinic	Massive, columnar and lameller	White and light green
Augite	Calcium, Magnesium, Iron and Al silicate.	,,	Prismatic crystals	Dark green to black
Rhodonite	Manganese silicate	Triclinic	Massive, cleavable to compact grains,	Rose red to pink or brown
Spodumene	Lithuim Al silicate	Monoclinic	Cleavable masses	White, grey, pink and green

Lustre	Clea-vage	Fracture	Hard-ness	Sp. Gr.	Remarks
Vitreous	Present	Uneven	5.5 to 6	2.2 to 2.3	—
Vitreous	Imper-fect	Uneven	5 to 5.5	2.5	Used as an orna-mental stone under the name "Lapis lazuli".
Vitreous to pearly	Perfect	Uneven	5.5	3.2 to 3.5	Exhibits bronze-like lustre. bronzite variety
,,	,,	,,	,,	,,	Variety of enstatite with more iron.
Vitreous	Imper-fect	Uneven	5 to 6	3.2 to 3.3	Transparent varie-ties used as gem-stones.
Vitreous	May be good	Uneven	5 to 6	3.2 to 3.4	—
Vitreous	Present	Uneven	5.5 to 6	3.4 to 3.7	Used as an orna-mental stone
Vitreous	Present	Uneven	6.5 to 7	3.1 to 3.2	Source of lithium. Some varieties are used as gemstones.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
4. Amphiboles.				
Tremolite	Calcium, Magnesium silicate.	Monoclinic	In radiating columnar aggregates and silky fibres.	Colourless to white
Actinolite	Ca Mg, Fe silicate.	Monoclinic	Radiating, fibrous	Dark green
Hornblende	Complex silicate of Ca, Na, Mg, Fe and Al.	,,	Prismatic, columnar, or fibous.	Dark green to black
5. Micas				
Muscovite	K, Al silicate	,,	Foliated	Colourless to light green or yellow.
Biotite	K, Mg, Fe and Al silicate.	,,	,,	Brown to black
Phlogopite	K, Mg, and Al silicate	,,	,,	Yellowish brown to copper red.
Lepidolite	K, Li and Al silicate	,,	Fine grained scaly aggregate	Pink to violet.
Vermiculite	K, Fe, Mg, Al Silicate	Monoclinic	Foliated, Granular	Yellowish Brown

Lustre	Clea-vage	Fracture	Hard-ness	Sp. Gr.	Remarks
Vitreous	Perfect	Uneven	5 to 6	3 to 3.3	A tough compact variety known as nephrite is used as an ornamental stone under the name Jade. The fibrous variety is known as asbestos.
Vitreous	Present	Uneven	5 to 6	3 to 3.3.	—
,,	Perfect	,,	,,	,,	—
Vitreous to pearly	Perfect basal	—	2 to 2.5	2.8 to 3.1	Known as white mica.
Vitreous to pearly	Perfect basal	—	2 to 2.5	2.8 to 3.1	Known as black mica.
,,	,,	—	2.5 to 3	2.9	Known as brown mica
,	,,	—	2.5 to 4	2.8 to 3	Known as pink mica. A source of lithium.
Pearly to Metallic	Perfect	—	2 to 2.5	2.5 to ?	Occurs as altered Products of Muscovite Phlogopite and Biotite; expands on heating.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
6. Other silicates.				
Olivine	Mg, Fe silicate	Ortho-rhombic	Saccha-roidal	Olive green
GARNET				
Pyrope	Mg, Al silicate			
Almandine	Fe, Al silicate			
Spessartite	Mn, Al silicate			
Grossularite	Ca, Al silicate	Isometric	Usually in dodecahedrons or trapezohedrons or in combinations of the two.	Usually brown to red. Also yellow, Green, pink.
Andradite	Ca, Fe silicate			
Uvarovite	Ca, Cr silicate			
Tourmaline	$R_9Al_3B_2(OH)$ Si_4O_{19}(R is Fe, Mg, alkalis)	Hexagonal Rhombohedral.	Columnar	Jet black
Beryl	Beryllium, Al silicate	Hexagonal	Columnar	Aquamarine, white, pink, emerald green.
Zircon	Zirconium silicate.	Tetragonal	In grains or crystals.	Shades of brown, green, red.
Topaz	Al silicate with Fluorine	Orthorhombic	In crystals, granular.	Colourless, wine yellow, blue green.
Andalusite	Aluminium silicate.	,,	Prismatic crystals.	Flesh red, brown or Olive green.

Lustre	Cleavage	Fracture	Hardness	Sp. Gr.	Remarks
Vitreous	Nil	Conchoidal	6.5 to 7	3.2 to 3.4	Clear green variety is used as gemstone under the name 'Peridot.'
Vitreous to resinous.	Nil Exhibits parting,	Uneven to subconchoidal.	6.5 to 7.5	3.5 to 4.3	Transparent varieties are used as gemstones.
Vitreous	Absent	Uneven	7 to 7.5	3 to 3.3	Vertical striations, Green and pink varieties used as gemstones.
Vitreous	Nil	Uneven	7.5 to 8	2.3	Source of beryllium (a strategic mineral) Transparent variety used as gemstone.
Adamantine	Nil	Uneven	7.5	4.7	Translucent to transparent, Used as a gemstone under the name Hyacinth.
Vitreous	Basal	Uneven	8	3.5 to 3.6	Transparent to translucent. Used as gemstone.
Vitreous	—	Uneven	7.5	3.2	Transparent variety serves as a gemstone.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Sillimanite	Aluminium silicate		Needle shaped crystals, fibrous	Colourless to white, pale green.
Kyanite	Aluminium silicate.	Triclinic	Bladed aggregates	Blue darker shade at centre.
Staurolite	Hydrous silicate of Fe and Al	Orthorhombic	Prismatic crystals.	Red brown to brownish black.
Vesuvianite	Hydrous silicate of Ca, Al, Mg & Fe	Tetragonal	Often in crystals, massive, granular.	Green or brown, yellow blue, red.
Epidote	Hydrous silicate of Ca, Al and Fe.	Monoclinic	In crystals, granular fibrous.	Pistachio green to blackish green.
Chlorite	Hydrous silicate of Mg, Fe and Al.	Monoclinic	Foliated massive.	Green of various shades.
Serpentine	Hydrous silicate of Mg.	Monoclinic	Massive, fibrous.	Yellow, green of various shades.
Talc	Hydrous silicate of Mg.	Monoclinic	Foliated massive. Also compact.	Apple green, grey, white.

Lustre	Cleavage	Fracture	Hardness	Sp. Gr.	Remarks
Vitreous	Perfect	Uneven	6 to 7	3.2	—
Vitreous pearly	Perfect	Uneven	4 & 7 in two directions	3.5 to 3.6	—
Resinous to vitreous, dull to earthy when impure.	Absent	Uneven	7 to 7.5	3.6 to 3.7	Often in cruciform twins.
Vitreous to resinous	Nil	Uneven	6.5	3.3 to 3.4	Also known as Idocrase. Used as semi-precious stone.
Vitreous	Present	Uneven	6 to 7	3.4	—
Vitreous, pearly	Basal	Uneven	2 to 2.5	2.6 to 2.9	—
Waxy	Nil	Sub-conchoidal	2 to 5	2.2 to 2.6	Fibrous variety known as Chrysotile asbestos.
Pearly to greasy	Basal	Uneven	1	2.7 to 2.8	Greasy feel.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Kaolin	Hydrous silicate of Al.	Monoclinic	Clay-like mass compact or friable.	White, often coloured by impurities.
Zeolites				
Natrolite	Hydrous silicate of Na and Al.	Monoclinic	Radiating crystal, massive fibrous.	Colourless or white tinted yellow to red.
Stilbite	Hydrous silicate of Na, Ca and Al.	Monoclinic	Sheaf-like aggregate.	White, yellow, brown, red
OXIDES				
Quartz				
Crystalline :				
Rockcrystal Amethyst Rose quartz Milky quartz Smoky quartz	SiO_2	Hexagonal	In crystals, aggregates, massive.	Colourless to white, violet smoky grey, rose red.
Crypto-crystalline:				
Chalcedony Agate Flint jasper Chert	SiO_2	—	Fibrous or granular.	Shades of blue, yellow, grey, green red.
Amorphous:				
Opal	SiO_2nH_2O	—	Massive, botryoidal stalactitic.	White, yellow green, grey, blue, red.

Lustre	Cleavage	Fracture	Hardness	Sp. Gr.	Remarks
Dull, earthy	—	Sub-con-choidal	2 to 2.5	2.6	Plastic when wet.
Vitreous to pearly	Present	Uneven	5 to 5.5	2.3	Occurs in cavities of volcanic rocks.
Vitreous to pearly	Present	Uneven	3.5 to 4	2.2	
Vitreous	Absent	Uneven to con-choidal.	7	2.6	Transparent to translucent.
Vitreous to resi-nous, some cases waxy.	Absent	Uneven to con-choidal	7	2.6	Agate shows fine parallel bands.
Vitreous to resinous	Absent	Con-choidal	5 to 6	2.2	Exhibits play of colours.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Corundum	Al_2O_3	Hexagonal	Prismatic crystals massive.	Shades of brown pink, blue, ruby red, green.
Hematite	Fe_2O_3	Hexagonal	Reniform, massive, fibrous, oolitic, micaceous.	Reddish brown to black.
Ilmenite	$FeTiO_3$	Hexagonal	Massive, compact, in grains.	Iron black
Magnetite	Fe_3O_4	Isometric	In crystals, granular, massive.	Iron black
Chromite	$FeCr_2O_4$	Isometric	Massive, granular.	Iron black to brownish black.
Chryso-beryl	$BeAl_2O_4$	Ortho-rhombic	Crystals	Various shades of green, brown, yellow.
Cassiterite	SnO_2	Tetragonal	Massive, granular, fibrous.	Brown or black
Rutile	TiO_2	Tetragonal	Compact, massive, slender, crystals.	Red to black

Lustre	Clea-vage	Fracture	Hard-ness	Sp. Gr.	Remarks
Vitreous to ada-mantine	Parting present	Uneven	9	4	Coloured transparent varieties used as gemstones. Black granular variety with iron oxide known as emery.
Metallic	—	Uneven to con-choidal	5.5 to 6.5	5.2	Red earth variety known as red ochre. Streak : cherry red.
Metallic	—	Uneven	5.5 to 6	4.7	Streak : black Magnetic after heating.
Metallic	—	Uneven	6	5.2	Strongly magnetic. Streak : black.
Metallic	Nil	Uneven	5.5	4.6	Streak : brown.
Vitreous	Present	Uneven	8.5	3.7 to 3.8	Used as a gemstone under the names "Alexandrite", "Cat's eye"
Adaman-tine to dull	Nil	Uneven	6 to 7	6.8 to 7	Streak : white. Also known as "tinstone"
Adaman-tine to metallic	Nil	Uneven	6 to 6.5	4.2	Streak : Pale brown.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Pyrolusite	MnO_2	Tetragonal	Granular, massive, reniform, dendritic.	Black
HYDROXIDES				
Goethite	Hydrous oxide of iron.	Ortho-rhombic	Massive, reniform, stalactitic, fibrous.	Dark brown
Limonite	Hydrous oxide of Fe.	—	Amorphous mammillary, stalactitic, nodular, earthy.	Various shades of brown, yellow.
Bauxite	Hydrous oxide of A1.	—	Amorphous, pisolitic, massive granular.	Dirty white, yellow, brown.
Psilomelane	Hydrous Oxide of Mn.	—	Amorphous, massive, botryoidal, stalacititic.	Black
CARBONATES				
Calcite	$CaCO_3$	Hexagonal	Rhombohedral crystals, massive, granular, stalactitic.	Colourless, white, brown, red, grey, blue, yellow.

Lustre	Cleavage	Fracture	Hardness	Sp. Gr.	Remarks
Metallic	Present	Uneven to sub-conchoidal.	1 to 2	4.8	Soils the fingers.
Adamantine to dull	Present	Uneven to sub-conchoidal.	5 to 5.5	4.4	Streak : yellowish brown.
Sub-metallic to earthy	–	Sub-conchoidal	5 to 5.6	3.6 to 4	Yellowish earthy variety known as "yellow ochre".
Earthy	Nil	Sub-conchoidal	1 to 3	2 to 2.5	—
Sub-metallic	Nil	Sub-conchoidal	5 to 6	3.7 to 4.7	Streak : black.
Vitreous	Perfect rhombohedral.	Uneven	3	2.7	Quickly effervesces with dilute HCl. Transparent crystalline variety known as "Icelandspar".

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Dolomite	$CaMgCO_3$	Hexagonal	Granular, compact.	Colourless, white, grey, green, brown.
Magnesite	$MgCO_3$	Hexagonal	Compact, massive, granular.	White, grey, brown.
Siderite	$FeCO_3$	Hexagonal	Granular, globular congregations.	Light to dark brown.
Rhodochrosite	$MnCO_3$	Hexagonal	Massive, granular.	Light pink to dark brown.
Malachite	Hydrous carbonate of copper.	Monoclinic	Botryoidal, stalactitic, massive.	Bright green
Azurite	Hydrous carbonate of copper	Monoclinic	Massive, nodular.	Sky blue
SULPHATES				
Barite	$BaSO_4$	Orthorhombic	Tabular, laminated, granular.	Colourless, white, grey, blue, red, yellow.
Celestite	$SrSO_4$	Orthorhombic	Radiating needles	Dirty white, faintly blue or red.

Lustre	Cleavage	Fracture	Hardness	Sp. Gr.	Remarks
Vitreous, pearly	Perfect	Uneven	3.5 to 4	2.9	Slightly effervesces with dilute HCl.
Vitreous earthy	Present	Uneven to con-choidal	3.5 to 5	3.1 to 3.2	Slightly effervesces with dilute HCI.
Vitreous	Present	Uneven	3.5 to 4.5	3.9	Slightly effervesces with dilute HCl
Vitreous	Present	Uneven	3.5 to 4.5	3.5 3.6	—
Adamantine to dull	Present	Uneven to sub-con-choidal	3.5 to 4	3.9 to 4	—
Vitreous to earthy	—	Con-choidal	3.5 to 4	3.7 to 3.8	—
Vitreous to pearly	Present	Uneven	3 to 3.5	4.5	Heavy amongst nonmetallic minerals. Hence known as "Heavyspar".
Vitreous to pearly	Perfect	Uneven	3 to 3.5	4	—

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Anhydrite	$CaSO_4$	Ortho-rhombic	Fibrous; granular, massive.	White, grey, blue
Gypsum	$CaSO_4 2H_2O$	Monoclinic	Foliated, massive, fibrous.	Colourless white, grey, shades of red, brown.
SULPHIDES				
Realger	AsS	Monoclinic	Granular	Red to orange.
Orpiment	As_2S_3	Monoclinic	Foliated, massive.	Fine lemon yellow.
Stibnite	Sb_2S_3	Ortho-rhombic	Radiating, granular.	Lead grey
Molybde-nite	MoS_2	Hexagonal	Foliated, granular	Lead grey
Galena	PbS	Isometric	Crystals, massive, granular.	Lead grey
Sphalerite	ZnS	Isometric	Massive, granular, fibrous.	Yellow, brown to black.
Cinnabar	HgS	Hexagonal	Massive, granular.	Red

Lustre	Clea-vage	Fracture	Hard-ness	Sp. Gr.	Remarks
Vitreous to pearly	Present	Uneven	3 to 3.5	2.9 to 3	—
Vitreous to pearly, silky.	Present	Uneven	2	2.3	Varieties : (1) Massive known as Alabaster, (2) Platy transparent crystals known as Selenite, (3) Fibrous form known as Satinspar.
Resinous	Present	Uneven	1.5 to 2	3.5	Streak : Orange red.
Resinous to pearly.	Present	Uneven	1.5 to 2	3.4 to 3.5	Streak : yellow.
Metallic	Present	Uneven	2	4.5 to 4.6	Streak : Lead grey.
Metallic	Perfect, basal	—	1 to 1.5	4.7 to 4.8	Streak : Lead grey.
Metallic	Perfect	Even or sub con-choidal	2.5	7.4 to 7.6	Streak : Lead grey.
Resinous to ada-mantine	Present	Con-choidal	3.5 to 4	3.9 to 4.2	Streak : brown.
Dull to adaman-tine.	Present	Uneven to sub-con-choidal	2 to 2.5	8	Streak : scarlet.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Pyrrhotite	Iron sulphide	Hexagonal	Massive, granular.	Reddish or brownish bronze.
Bornite	Cu, Fe, sulphide.	Isometric	Massive	Red to brown
Chalco-pyrite	$CuFeS_2$	Tetragonal	Massive, granular.	Brass yellow often with tarnished appearance.
Pyrite	FeS_2	Isometric	Crystalline, aggregates massive, nodular.	Bronze yellow.
Marcasite	FeS_2	Ortho-rhombic	Nodular, massive, tabular.	Bronze yellow.
Arseno-pyrite	FeAsS	Ortho-rhombic	Massive	Silver white.
HALIDES				
Halite	NaCl	Isometric	Crystals, massive, granular, fibrous.	Colourless white, yellow, brown, red, grey.

Lustre	Clea-vage	Fracture	Hard-ness	Sp. Gr.	Remarks
Metallic	Present	Uneven to con-choidal	3.5 to 4.5	4.4 to 4.6	Streak : greyish.
Metallic	—	Uneven to con-choidal	3	4.9 to 5.4	Becomes iridescent. Known as "peacock ore".
Metallic	—	Con-choidal, uneven	3.5 to 4	4.1 to 4.3	Streak : shining greenish black.
Metallic	—	Con-choidal, uneven	6 to 6.5	4.8 to 5	Streak : black, crystal faces often striated.
Metallic	—	Uneven	6 to 6.5	4.9	Streak : grey.
Metallic	Present	Uneven	5.5 to 6	5.9 to 6.2	Streak : greyish black.
Vitreous to resinous	Perfect	Con-choidal	2 to 2.5	2.2	Tastes saline.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
Fluorite	CaF_2	Isometric	Crystals, granular.	Colourless, white, green, purple, yellow, blue.
Cryolite	Na, Al Fluoride.	Monoclinic	Massive lamellar.	Colourless, snow white, brown, red.
PHOSPHATES				
Apatite	Ca, phosphate with Cl and F.	Hexagonal	Crystals, massive.	Sea green, yellow, red, blue.
Monazite	Phosphate of cerium metals with thorium.	Monoclinic	Massive, rolled grains.	Pale yellow to dark reddish brown.
TUNGSTATE				
Scheelite	Calcium tungstate.	Tetragonal	Massive, granular	Yellowish white or brownish white.
URANATE				
Pitchblende	Uranium mineral.	Isometric	Massive, granular, botryoidal.	Black, grey, browr

Lustre	Clea-vage	Fracture	Hard-ness	Sp. Gr.	Remarks
Vitreous	Present	Uneven to con-choidal	4	3.1 to 3.3	Transparent to translucent.
Vitreous	Present	Uneven	2.5	3	—
Vitreous to resinous	Poor	Con-choidal	5	3.2	Resembles beryl; Distinguished by its low hardness.
Resinous	Imper-fect	Con-choidal, uneven	5.5	5.3	Strategic mineral, Radioactive. Use-ful in production of atomic energy.
Vitreous	Present	Uneven	4.5 to 5	6	—
Sub-metal-lic, greasy, pitch-like	—	Uneven	5.5	6.4 to 9.7	Strategic mineral, Radioactive. Use-ful in the produc-tion of atomic energy.

Name of the mineral	Chemical composition	System of crystallisation	Form	Colour
NATIVE ELEMENTS				
Diamond	C	Isometric	Crystals, in grains.	Colourless. white, yellow red, green blue black.
Graphite	C	Hexagonal	Laminated, scaly aggregates.	Grey
Sulphur	S	Ortho-rhombic	Massive, granular	yellow
Gold	Au	Isometric	Massive granular.	Bronze yellow
Copper	Cu	Isometric	Massive, irregular.	Copper red
Platinum	Pt	Isometric	Irregular lumps and in grains.	White, steel grey

Lustre	Cleavage	Fracture	Hardness	Sp. Gr.	Remarks
Brilliantly-adamantine.	Perfect	Conchoidal	10	3.5	Black compact variety is known as "Bort" or 'Carbonado". Used for cutting and grinding purposes.
Metallic	Basal	—	1 to 2	2 to 2.3	Streak : black and shiny, greasy feel.
Resinous	Imperfect	Conchoidal	1.5 to 2.5	2.1	Smells sulphurous.
Metallic	—	Hackly	2.5 to 3	15 to 19.3	Streak : golden yellow. Variation in Sp. Gr. is due to association.
Metallic	Nil	Hackly	2.5 to 3	8.8	Streak : metallic and shining.
Metallic	—	Hackly	4 to 4.5	14 to 21.46	Streak : white, steel grey.

QUESTIONS

Group-A.

I. Match the word or phrase in the left column with the correct word in the right column.

1. Asbestos	*a.* Felspathoid
2. Garnet	*b.* Metallic lustre
3. Streak	*c.* Pearly lustre
4. Flourescence	*d.* Taste
5. Talc	*e.* Rhombohedral cleavage
6. Calcite	*f.* Brittleness
7. Sulphur	*g.* Dodecahedral crystal
8. Rock Salt	*h.* Ultraviolet light
9. Felspar	*i.* Silky lustre
10. Nephelene	*j.* Powder of a mineral
11. Gemstone	*k.* Ceramic industry
12. Galena	*l.* Corundum

II. Give the name of the mineral described in each of the following groups of phrases.

1. Granular in form, used as gemstone under the French name 'Peridot'
2. SiO_2, six sided crystal, transparent to translucent, Violet in colour, high hardness.
3. Lustre resinous, colour bright yellow, brittle in nature, native element.
4. Fibrous in form, low hardness known as satinspar.
5. Colour lead grey, specific gravity high, hardness low, lustre —metallic, cleavage—cubic.
6. Decomposed feldspar, white in pure form, hydrous aluminium silicate, very soft.
7. Lustre—metallic, pure carbon, used in pencils, used as a lubricant.
8. Pale green, Foliated, greasy feel, softest mineral, cosemetics.
9. $CaCO_3$—Double refraction, Rhombohedral cleavage, transparent crystal.
10. Columnar form, vertical striations, commonly jet black in colour, high hardness.

III. Pick out the related terms, in each group giving reasons.

a. Quartz, Semiprecious stone, Amethyst, Cleavage.

b. Muscovite, Percussion figure, high hardness, insulator.

c. Garnet, Almandine, Dodecahedron, fibrous form.

d. Orthoclase, Enstatite, Microcline, Moonstone.

e. Bornite, Peacock ore, Iridiscence, soils the fingers.

Group-B

I. Describe the tests you would perform in trying to identify a mineral in the field.

II. What are Rock forming minerals? Give a general account of their Chemical and physical properties.

(*a*) Define the term 'crystal'.

(*b*) What are symmetry elements in crystals?

(*c*) Name the six crystal systems, with their axial disposition and give two mineral examples for each system.

III. Describe the following groups of minerals
a. Quartz group b. Felspar group c. Mica group

IV. Compare and contrast the minerals of Pyroxene group to that of Amphibole group.

V. Explain how will you distinguish the following pairs of minerals

a. Pyrite and chalcopyrite
b. Beryl and Apatite
c. Hornblende and Augite
d. Calcite and Gypsum
e. Muscovite and talc.

VI. Write short notes on :—
(*a*) Kinds of lustre (*b*) Twincrystals (*c*) Moh's scale of hardness (*d*) Flourescence (*e*) Cleavage and parting (*f*) Walker's steel-yard balance.

VII. Mention the most distinguishing physical properties of the following minerals.
Amethyst, Olivine, Talc, Labradorite, Galena.

VIII. Give the principal ores, their physical properties, Chemical composition and distinguishing characters of the following metals.
1. Iron 2. Copper 3. Manganese 4. Zinc 5. Aluminium 6. Lead.

IX. (*a*) State the systems of crystallisation and crystal forms present in the following minerals.
a. Zircon *b*. Pyrite *c*. Calcite *d*. Beryl *e*. Olivine *f*. Gypsum *g*. Galena
(*b*) Illustrate their symmetry elements by means of stereographic projections.

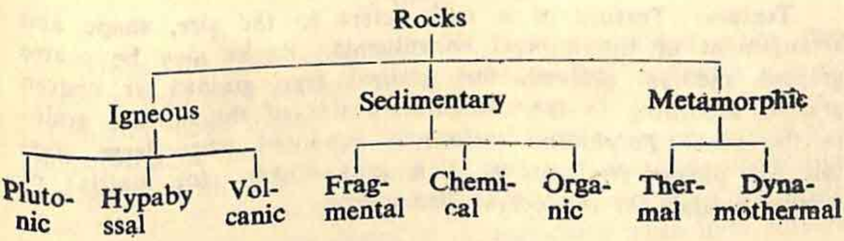
CHAPTER IV

PETROLOGY

Introduction: Petrology is the science of rocks which form the units of earth's crust. Rocks are composed of minerals. Some of the rocks are monomineralic (e.g., dunite or olivine rock made up of one mineral), but most of them contain two or more minerals.

Composition of earth: It is considered that the earth is made up of three layers consisting of (1) interior-most Ni and Fe metallic core surrounded by (2) a layer of denser silicates with (3) a slaggy crust floating over them. This conception has been developed by the study of meteorites or shooting stars and seismic observations. The outer crust of the earth to a depth of about 10 miles consists of *igneous* and *metamorphic* rocks with a thin mantle of *sedimentary* rock resting on them. Whatever be the origin of the earth it is certain that all parts of the original surface of the earth passed through a molten stage and the first solid material was derived from this molten material known as magma.

Classification of rocks:



Rocks formed by the consolidation of magma are said to be *primary* or *igneous* rocks. After the consolidation of original crust and formation of the hydrosphere and atmosphere, water and wind began to attack the primary rocks and disintegrate them so that the sediments began to accumulate in the hollows of the crust. These sediments were subsequently consolidated into rocks which are known as *secondary* rocks. These rocks are also known as *aqueous*

rocks. Finally primary and secondary rocks were subjected to earth movements which carried them down to the earth's crust where they were acted upon by heat and pressure. By these agencies the rocks were partly or wholly reconstituted and such rocks more or less completely changed from the original conditions are known as the *metamorphic* rocks. According to the mode of origin all rocks may be assigned to three major groups, (1) Igneous, (2) Sedimentary and (3) Metamorphic.

Rocks are distinguished on the basis of structure, texture and mineral composition and other physical properties like hardness and fracture in hand specimens, the study being known as *megascopic* study. Chemical analysis and microscopic examination are also necessary to identify some of the less common types.

Structure: Structure is a term used to refer to the larger features of rock. Igneous rocks are usually massive, i.e., without any directional arrangement in the mineral constituents. Sedimentary rocks are usually stratified or laminated. It is further distinguished by the frequent occurrence of organic remains or fossils and such other marks indicative of deposition in the sea or land. Metamorphic rocks are massive, banded and stratified according as they are from igneous or sedimentary rocks. Thorough recrystallisation of sedimentary rocks may, however obliterate the stratification, or direct pressure may produce in igneous rocks banded, foliated and slaty structure resembling stratification.

Texture: Texture of a rock refers to the size, shape and arrangement of the mineral constituents. Rocks may be coarse grained, medium grained, fine grained even grained or uneven grained according to the comparative size of the mineral grains in the rock. *Porphyritic* texture is produced when large crystals (or phenocrysts) occur in a groundmass (or matrix) of smaller crystals (or microcrystalline grains).

Hardness is also useful to distinguish the soft rock like limestone, shale and talc schist from others which are hard.

Fracture: Fracture is an important feature in the case of glassy rocks which break with good conchoidal fracture.

Rocks should be studied in the field and laboratory. In the

field one should study the shape, relation of rock mass with other rock masses whereas representative specimens collected from the rock should be properly identified in the laboratory by microscope and chemical tests, if necessary.

IGNEOUS ROCKS

Igneous rocks are formed by the solidification of the cooling magma which intruded into the older rocks or which extruded on the surface as lava flow. Thus arise *intrusive* and *extrusive* rocks. Intrusive rocks are divisible into plutonic and hypabyssal according as they are found at great or low depths below the earth's surface. These rocks are now exposed on the surface due to the removal of overlying cover or roof of older rocks by agents of denudation.

Igneous rocks are often classified as acid and basic; acid when they are rich in silica and alumina and basic when they are rich in iron oxide and magnesia. Acid rocks are lighter in colour and lighter in weight than the basic rocks. The mineralsoccurringin igneous rocks may be classed as essential, accessory and secondary. Essential minerals are those which are necessary to the diagnosis of the rock type and they form a major part. Accessory minerals are those whose presence or absence has no bearing on the nomenclature of rocks. Secondary minerals are those formed by weathering or metamorphism or those introduced by circulating solutions.

PLUTONIC ROCKS

Under plutonic conditions crystallisation takes place deep-seatedly with slow cooling under great pressure and with retention of volatile constituents. Hence the texture of plutonic rocks is holocrystalline and coarse. The mineral grains are big enough to be recognised with naked eye and is described as phanerocrystalline. The colour of the rocks depends to a large extent on its mineral composition. They are described as leucocratic when light coloured and melanocratic when dark coloured.

Classification:

Acid—Granite.
Intermediate—Diorite.

	OVERSATURATED			SATURATED			UNDERSATURATED		
	I	II Quartz+Felspars		III Felspars only			IV Felspars + felspathoids	V Felspathoids only	VI Mafic minerals
	Quartz	Orthoclase	Plagioclase	Predominant alkali felspars	Soda lime plagioclase	plagioclase Lime soda			
PLUTONIC	Igneous quartz vein	Granite	Granodiorite	Syenite	Diorite	Anorthosite, gabbro, norite	Nepheline syenite, leucite syenite.		Periodotite pyroxenite.
HYPABYSSAL		........................Porphyries......	....	....	....	....	....		
						Dolerite			
		.......................Pitchstone.........	....	....	....	....			
VOLCANIC		Rhyolite	Dacite	Trachyte	Andesite	Basalt	Phonolite	Nepheline, leucite basalts.	Olivine rich basalt.
		........Obsidian.........							
Average silica %	90	72	66	59	57	48	44.5	43	41

CLASSIFICATION OF IGNEOUS ROCKS

Basic—Gabbro.
Ultrabasic—Peridotite, Dunite.

Granites : Granites occur as batholiths, stocks, bosses and dykes.

Colour : Light in colour with a white or pink tint according to the colour of the felspar.

Texture : Holocrystalline and phanerocrystalline. Coarse to fine grained. Some varieties show prophvritic texture.

Minerals : Quartz and felspars are the essential minerals. The felspar, usually orthoclase, predominates. Mica is also commonly present and may be a dark variety like biotite or the light mica, muscovite or both. Other minerals which may be present in different granites are hornblende, augite and tourmaline. Accessory minerals include apatite, zircon, sphene, garnet and magnetite.

Varieties of granite are named according to the chief mineral present other than quartz and felspars and include *muscovite granite, biotite garnite, muscovite biotite granite, hornblende granite, tourmaline granite.* Tourmaline granite is also known as schorl rock or luxullyanite. The other varieties are *pink granite* in which felspars belong to the flesh red orthoclase variety and *porphyritic granite* which exhibits porphyritic texture. *Pegmatite* or *graphic granite* which is chiefly composed of quartz and felspars exhibits graphic texture due to the intergrowth of quartz and felspars. Pegmatite rocks which often occur as dykes and veins are of great economic importance as they contain rich deposits of mica, beryl, topaz, pitchblende and apatite. Large crystals of quartz and felspars present in these rocks serve as raw materials for ceramic industry, e.g., Mica belt of Nellore in the Andhra State and Hazaribagh in Bihar.

Granite serves as an excellent building stone among the igneous rocks because of its good appearance, hardness, resistance to weathering and compressive strength. Its strength and rough fracture are also valuable properties when it is used as a concrete

aggregate. The average specific gravity of granite is 2.67. The term granite is used commercially for many rocks which are not granites in the geological sense, e.g., diorite and gneiss.

Granodiorites : Similar in appearance to granite. Chiefly composed of quartz, felspars and dark minerals. The felspars usually belong to plagioclase variety and quartz is less in amount than in granite.

Syenites : These are not very abundant in occurrence in comparison to granites.

Colour : Light coloured.

Structure
Texture } Same as granite.

Minerals : Chiefly composed of orthoclase in large amounts with small amounts of plagioclase and dark minerals, hornblende, biotite and augite. Accessory minerals include iron oxides, apatite, sphene and zircon.

Varieties : Felspathoids occur in alkali-rich syenites when they are distinguished as *nepheline syenite, sodalite syenite* etc. Normal syenites are distinguished as *hornblende syenite, augite syenite* and *biotite syenite* after the predominating ferro-magnesian mineral. *Corundum syenite* is another variety which results due to more alumina content and relatively less alkali content in the magma during the process of crystallisation. These rocks are found in the Sivamalai Hills in the Coimbatore District of Madras and Kishengarh in Rajasthan.

Use : For construction and other uses syenite has the same value as granite.

Diorites :

Colour Dark coloured.

Texture : Holocrystalline and phanerocrystalline. Usually fine grained.

Minerals : Essential minerals are plagioclase felspars and hornblende. Accessories include iron oxide, apatite and sphene Biotite, quartz and orthoclase may be present in small amounts.

Varieties : Biotite diorite, augite diorite and quartz diorite. Average specific gravity of diorite is 2.87.

Use : Serves as road metal.

Gabbros :

Colour : Dark coloured.

Texture : Holocrystalline and phanerocrystalline. Usually coarse grained.

Minerals. Essential minerals are plagioclase felspars (labradorite to anorthite) and a monoclinic pyroxene, augite. Other minerals which may be present include enstatite or hypersthene, olivine, hornblende and biotite. Ilmenite and apatite are common accessories.

Varieties : These are named after the chief ferro-magnesian minerals present other than augite, e.g., hypersthene gabbro and hornblende gabbro. Norite is a gabbro containing enstatite or hypersthene instead of augite. Specific gravity of the rock ranges from 2.9 to 3.2.

Use : Serves as road metal.

Peridotites :

Colour : Dark coloured.

Texture : Holocrystalline and phanerocrystalline. Coarse to fine grained.

Minerals : These rocks consist essentially of mafic minerals and contain little or no felspars. As they are less rich in silica content they are known as ultrabasic rocks.

Varieties : *Peridotite* in which olivine is the chief constituent is named from the French peridot-olivine. Other minerals include augite, hornblende, biotite and iron oxides. Felsic minerals are virtually absent.

A variety composed almost entirely of olivine is called *dunite*.

Other kinds of ultrabasic rocks are those which consist almost entirely one kind of mafic mineral such as *pyroxenite* (all

pyroxene) and *hornblendite* (all hornblende). Specific gravity ranges from 3 to 3.3.

Importance. Fairly large economic deposits of chromite and magnesite are found in association with dunite intrusions as in Mysore and Salem. These rocks also contain other metalliferrous ores of nickel and platinum. Mica perioditites form the parent rock for diamond in the Kimberlite diamond mines of South Africa. They form the neck of old volcanoes.

HYPABYSSAL ROCKS

The hypabyssal rocks form a link between plutonic and volcanic rocks. They are distinguished from the volcanic rocks by their intrusive character, and from the plutonic rocks by their occurrence as minor intrusions such as dykes and sills. They exhibit special micro-structures due to rapid cooling. The hypabyssal rocks often show porphyritic texture and are more allied to volcanic rocks in texture.

Classification :

Acid—Granite porphyry.
Intermediate—Syenite porphyry.
Basic—Dolerite.

Granite and syenite porphyries correspond in their mineral composition to their plutonic equivalents, but has a porphyritic fabric.

Granophyre, a microgranite showing graphic intergrowths between the quartz and felspars.

Felsite is produced by the reduction of the grain-size to micro or cryptocrystalline dimensions, and it ranges from acid to basic varieties.

Dolerite : Occurs as dykes and sills.

Colour : Dark coloured.

Texture : Aphanitic. Usually medium to fine grained.

Minerals : Same as gabbro.

Use : Finds use as crushed stone for road metal and concrete aggregate because of its toughness and strong resistance to abrasion.

Dolerite resembles to a great extent basalt, a volcanic rock in hand specimens, but it can be easily distinguished under the microscope by its characteristic *ophitic texture* produced by the occurrence of lath-shaped felspars enclosed by ferro-magnesian minerals.

VOLCANIC ROCKS

Volcanic rocks are formed on the surface either by the consolidation of the lava or by the accumulation of volcanic fragments.

Structure and Texture. The mineral constituents in volcanic rocks cannot be distinguished with naked eye. This kind of texture is termed *aphanitic*. The rapid cooling or chilling of lava gives rise to *glassy* or vitreous rocks, in which none of the constituents is crystallised. Volcanic rocks may also be vesicular or scoriaceous, i.e., full of cavities or bubble holes formed due to the escape of volatile constituents, e.g., pumice and scoria. In some cases these cavities get filled with secondary minerals like quartz, calcite, zeolite and chlorite. These infillings are described as amygdales because of their fancied resemblance to almonds and the structure as amygdaloidal. This structure is commonly exhibited in basalts.

Fragmental or pyroclastic rocks are composed of volcani fragments and dust thrown out from the volcano.

The important types of volcanic rocks are the rhyolite, obsidian, pitchstone, trachyte, phonolite, andesite and basalt.

Rhyolite : This is glassy or cryptocrystalline and may contain phenocrysts of quartz and orthoclase. It frequently contains spherulitic structures which are minute spheres of crystalisation formed of quartz and felspar crystals radiating from centre. It exhibits distinct flowage bands.

Obsidian is a variety of rhyolite, black in colour, and glassy in

texture breaking with a conchoidal fracture. Thin edges sometimes show parallel flow bands.

Pitchstone is another variety of rhyolite, glassy in texture generally with a greenish tint and pitch like lustre.

Pumice is a highly vesicular lava froth formed by escaping gases and is so light as to float on water. Pumice may have the composition of rhyolite or it may be of more basic character. In modern times this is used in light concrete slabs for sound insulation.

Trachyte This is a pale coloured rough looking rock. It has phenocrysts of orthoclase in a ground mass composed mainly of felspars with some biotite or hornblende as a mafic constituent. A glassy base is sometimes present.

Sanidine trachyte contains porphyritic crystals of sanidine, a glassy variety of orthoclase.

Phonolite is a felspathoidal trachyte. It is a light grey earthy looking rock.

Andesite : Essential constituents are plagioclase (generally andesine) and a mafic mineral (hornblende, augite, enstatite or biotite) which occurs as porphyritic crystals in a base which may be glassy or cryptocrystalline.

Varieties : Hornblende andesite, biotite andesite. augite andesite and quartz andesite.

Use : Serves as road metal.

Basalt : This is a dense looking black rock, often weathering to a brown colour and is the commonest of all the lavas.

Texture : Aphanitic. Porphyritic, vesicular, amygdaloidal.

Minerals : Essential minerals are plagioclase and augite. Magnetite and ilmenite are common accessories. Olivine occurs in many basalts and commonly shows alteration to serpentine.

Varieties : Olivine basalt and amygdaloidal basalt.

Use : Serves as a road metal and concrete aggregate. Fragmental igneous rocks represent the material that was blown out by volcanoes during explosive activity. The explosive action in a volcano is due to gases, chiefly superheated steam contained under pressure in the magmas. They include bombs, lapilli and dust or ash.

Bombs are lumps of lava forced off the ascending liquid magma by the current of issuing steam. They are spherical in form and are larger in size than lapilli.

Lapilli are angular fragments of lava similarly forced off by the issuing steam.

The finest material is known as *dust* or *ash*. When the finer materials, dust or ash, get compacted the resulting rock is known as *tuff*.

Agglomerate is a volcanic rock formed due to accumulation of spherical bodies like bombs.

Volcanic breccia is formed due to accumulation of angular fragments like lapilli.

SEDIMENTARY ROCKS

The sedimentary rocks are made up of fragments and particles derived from older rocks. They are usually bedded or stratified. They also show cross-bedded or false-bedded structure and ripple marks. Further many sedimentary rocks are fossiliferous. The texture of a sedimentary rock depends upon the condition under which the sediments were deposited e.g.,. a coarse grained sedimentary rock indicates shallow water deposition. Similarly a coarse grained chemically formed rock indicates that the crystallisation of the material dissolved in water took place under favourable conditions.

Classification :

1. *Fragmental or sedimentary deposit.* Formed by the cementation of fragments of pre-existing rocks which may be residual products of weathering or may be transported by air, water or ice.

2. *Chemical deposits :* Formed by the precipitation of materials dissolved in sea-water, lake water or in circulating water.

3. *Organic deposits :* Formed by the accumulation of organic remains or through the agency of organisms.

FRAGMENTAL DEPOSITS

a. Pebbly or rudaceous deposits e.g., conglomerate and breccia.

b. Sandy or arenaceous e.g., sandstone, grit and arkose.

c. Clayey or argillaceous e.g., shale and clay.

Conglomerate : This is formed due to consolidation of rounded pebbles or gravels with some cementing material. The cementing material may be silica, iron oxide or calcium carbonate.

Breccia : This is composed of angular fragments of disintegrated rocks by some cementing material.

Sandstone : This is formed due to consolidation of sand grains with some cementing material which is usually either silica or iron oxide or carbonates. Bedding planes and joints which develop in the consolidated rocks and form surfaces of division, break the mass into roughly rectangular blocks and are very useful for quarrying. The varieties, named after the chief cementing material, are *siliceous* sandstone, *ferruginous* sandstone, *calcareous* sandstone and *argillaceous* sandstone.

Sandstone is of uniform grains and usually light coloured and is extensively used as a building stone.

Arkose is a variety of sandstone with angular and rather coarse grains of felspars in addition to sand grains. It is otherwise known as *felspathic* sandstone.

Grit is a coarse textured sandstone in which sand grains are bigger in size.

Laterite : This is a product of tropical alteration of the igneous and metamorphic rocks. Laterite is a porous, pitted, clay-like

rock with red, yellow, brown, grey and mottled colours. It is usually either ferruginous or aluminous in composition. In India, it is used as a building stone because of the facility with which it is cut into bricks or blocks when freshly quarried and its property of hardening with exposure to air (Hence the name laterite meaning brick from Latin word *later*—brick).

Shales : Shales are compacted clays and possess a finely laminated structure by virtue of which they are fissile and break easily into parallel sided fragments. Shale is formed due to compaction of clay. When it does not exhibit good lamination the rock is called *mudstone*. Shales are distinguished into the following types on the basis of their chemical composition : (1) Argillaceous, (2) Arenaceous, (3) Calcareous, (4) Carbonaceous, (5) Bituminous and (6) Oily.

Clays : Clays have a complex mineral composition. Different varieties of clays are as follows :—

1. *Fuller's earth* is a pure clay ot low plasticity which disintegrates in water. It readily absorbs grease and is used for bleaching and filteration of oils, for cleaning cloth and taking grease out of wool and for medical purpose.

2. *Bentonite* is a clay derived from the alteration of volcanic dust and ash deposit and is mainly composed of montmorillonite $[Al_4Si_8O_{20}.(OH)_4]$. Bentonite clays swell enormously on the addition of water yielding a viscous mass. This property renders the material useful for various purposes such as the thickening of drilling mud in sinking of oil wells; it is also used in America as an ingredient of moulding sand for foundries and as an absorbent in many processes. Bentonite has been employed as a sealing layer in trenches and cofferdams to prevent the percolation of water and as a slurry pumped into sand or gravels to fill the voids and render the mass impervious.

3. *Fire clays* occur beneath coal seams and characteristically have a very low content of alkalies. They can be exposed to high temperatures without melting or disintegrating and are used in the manufacture of refractories.

4. *Alluvial Clay* is red silty clay formed in the river beds and useful in making bricks, tiles, terracotta and earthenware.

5. *China clay* (*or kaolin*) is a pure white clay consisting in the raw state of the mineral kaolinite formed due to decomposition of felspars. It is used for the manufacture of China ware or procelain ware.

Apart from uses mentioned above clays and shales are used in the cement manufacture.

CHEMICAL DEPOSITS

Chemical deposits are mainly formed due to physico-chemical processes such as evaporation and precipitation.

Concretions : Rounded and nodular masses of rock differing in chemical and mineral composition from the enclosing rocks are called concretions. They often exhibit concentric structure around some nucleus, fossil or inorganic fragment, e.g., phosphatic nodule.

Secretions are formed of substances due to deposition in the cavities of rock by percolating solutions, e.g., druse and geoid.

Dendrites are secretionary forms of iron and manganese oxides occurring as delicate growths resembling moss or small plants. They occur as coating on the fine grained limestones.

Siliceous deposits. Hot-springs or geysers deposit around the orifice of eruptions in mounds or terraces silica material and that is known as *siliceous sinter*. It is cryptocrystalline or opaline form of silica.

The cryptocrystalline forms of silica like flint and chert are also of sedimentary origin formed by the action of percolating solutions.

Carbonate deposits : These are formed due to precipitation of substances in solution, due to escape of carbon dioxide or rise of temperature or both, e. g., *stalactites* and *stalagmites* formed by the evaporation of water dripping from the roofs of limestone caves

and flowing over their floor. Stalactites are the long icicle like pendants from the roof and stalagmite is the material formed on the floor of the cave.

In the same way are formed from spring waters certain porous, cellular limestones. These are known as *calc-tufa, calc-sinter* or *travertine*.

Kankar : This is commonly found in tropical countries as irregular concretions of impure calcareous matter in alluvial plains and below the soil. They often occur as lumps or nodules.

Other important deposits of chemical origin are rock salt and gypsum, e.g., rock salt deposits of Punjab and gypsum deposits of Tiruchirapalli.

ORGANIC DEPOSITS

Organic deposits are formed due to the vital activities of animals and plants or due to the accumulation of their shells and other parts. They may be classified as follows on the basis of their chemical composition.

1. *Calcareous*—Fossiliferous limestone, oolitic limestone.
2. *Phosphatic*—Phosphatic nodules, guano.
3. *Ferruginous*--Bacterial iron ore, oolitic hematite.
4. *Siliceous*—Diatom oozes, diatomaceous earth.
5. *Carbonaceous*—Coal, peat etc.

Limestone : Limestone consists essentially of calcium carbonate and is formed organically or chemically. Impurities commonly present in limestone include clay, silica in the form of quartz grains and other hard detrital grains. The varieties are as follows :

1. *Shelly limestone or fossiliferous limestone*—a rock chiefly composed of shells of marine organisms such as brachiopods and lamellibranchs.

2. *Coral, algal and crinoidal limestones*—taking their names from prominent fossil constituents.

3. *Chalk*—a soft white limestone made of finely divided calcium carbonate containing the remains of minute marine organism such as foraminifera.

4. *Oolitic limestone or oolite*—made up of rounded grains formed by the deposition of successive coats of calcium carbonate around a nucleus such as a grain of sand or a piece of shell.

5. *Dolomitic limestone and magnesium limestone*—rocks which contain magnesium carbonate in addition to calcium carbonate.

Limestone serves as chief raw material in cement manufacture.

Phosphatic Nodule : This is a sedimentary deposit which is nodular in form, externally smooth, internally fissured and often filled with calcite and gypsum. It occurs in the cretaceous rocks of Tiruchirapalli and is used as a fertilizer.

Guano : This is another phosphatic deposit of directly organic origin. Fish-eating sea birds live in great flocks on small islands for safety and the guano of commerce is obtained from accumulations of their excrement. This is a very soluble substance. Hence, it is only preserved on islands in regions which are practically rainless. This valuable manure is limited to certain islands of the western coasts of South America, South Africa and Australia, the main supply coming from islands of the Peruvian coast.

Bacterial Iron Ore : This is formed due to the vital activities of certain lowly organisms of algal and bacterial character.

Oolitic Hematite : This is also formed due to the action of iron bacteria which have the power of extracting iron from solution and depositing it as ferric oxide around their cells.

Diatom Oozes, Diatomaceous Earth : These are of some commercial importance as abrasives and polishing materials and used as absorbents in the manufacture of high explosives and also in the purification of wine.

Coal, Peat etc. : These include the deposits formed due to accumulation of large amounts of plant debris, in various stages of

alterations. Peat, lignite, coal, anthracite, cannel and boghead belong to this group.

Peat is the first stage in the process of coal formation. It is found in temperate and cold regions and is rare in the tropics.

Lignite or brown coal is more solid than peat but less compact than coal. It may be of any tint between brown and black and retains a distinct fibrous woody structure. It represents an intermediate stage between wood and coal. The common varieties of coal are well jointed, break into rectangular lumps and finely laminated in structure.

Anthracite is the hard variety of coal with semi-metallic lustre and conspicuous conchoidal fracture. Of all coals, it is the richest in carbon and poorest in volatile materials.

Cannel coal is dull black compact variety of coal with pitch like appearance and conchoidal fracture. The name cannel refers to its property of easy ignition and burning with a bright smoky flame like a candle. Cannel coals contain a considerable amount of mineral matter or ash and if this increases in amount over the carbonaceous matter, cannel passes into oil shale. Cannel coals are formed by some chemical processes acting upon spore-rich vegetable slime or on accumulation of oil-rich algae

METAMORPHIC ROCKS

Metamorphic rocks are those rocks which have undergone some chemical or physical change subsequent to their original formation. The word metamorphic means "change in form" and metamorphism is used as a general term for all those changes by which the original character of rocks is more or less completely altered.

The changes which occur in metamorphism are the result of the addition of heat or the operation of pressure or both with the action of the chemical agents. Large scale changes in temperature, pressure and chemical environments upset the physical and chemical equilibrium of the mineral assemblage and

metamorphic changes take place as a result of the effort to establish a new equilibrium. The constituent minerals of a rock are changed into others which are more stable under new conditions and with a new structural arrangement better suited to new conditions.

The structure and mineral composition of a metamorphic rock depends on the composition of the original rock and the kind of metamorphism to which it has been subjected. In addition to minerals commonly found in igneous or sedimentary rocks there are certain minerals which are common in metamorphic rocks only. Minerals characteristic of metamorphic rocks are tremolite, kyanite, staurolite, talc, serpentine, mica and chlorite. The banded or the laminated character given by the parallel arrangement of its minerals is the most striking peculiarity of a metamorphic, rock. There are two broad classes of metamorphism, viz., thermal metamorphism and dynamo thermal metamorphism.

Thermal Metamorphism : Here heat is the dominant factor. This is due (1) to the increase in depths below the surface and (2) to the magmas which intrude into crystal layer or country rock. The country rock or the original rock is soaked with gaseous or liquid emanations from intruding magma and this brings about the mineral transformation. Where there is no change in the bulk composition the thermal metamorphism is known as *contact metamorphism* and where there is addition of magmatic material to the metamorphosed rocks it is known as *additive* or *pneumatolytic metamorphism.*

Dynamo Thermal Metamorphism : The combination of pressure and heat form one of the most powerful metamorphic forces leading to more or less complete recrystallisation with new structures. Because this kind of metamorphism is associated with mountain building processes, it is known as dynamo thermal metamorphism. Typical rocks of this metamorphism are schists and gneisses.

Mylonite : During stress metamorphism, due to extreme conditions rocks get completely pulverised and rolled out and they are termed mylonite.

Palingenesis : In regional metamorphism, when igneous bodies inject, due to extreme conditions result complete mixing and melting of rocks with the production of new bodies of magma. These again form intrusive rocks. This process of regeneration of magma is termed palingenesis.

Uralitisation : At the early stages of metamorphism, usually ferromagnesian minerals get altered to chlorite and that is known as *chloritisation*. By further metamorphism, hornblende is produced from pyroxene with epidote or zoisite and quartz occurring as byproducts. This process is known as uralitisation.

The most common type of metamorphic rocks are gneiss, quartzite, slate, various schists, crystalline limestone and marble.

CLASSIFICATION OF METAMORPHIC ROCKS

Structure & texture	Composition	Rock name
Massive, banded consisting of alternating lenses.	Various tabular, prismatic and granular minerals (frequently elongated).	Gneiss.
Granular, consisting mostly of equidimensional grains.	Calcite, dolomite, quartz, in small particles.	Marble. quartzite.
Foliatdd or piaty.	Various tabular and prismatic minerals generally elongated.	Schist, serpentine rock, slate, phyllite.

Gneiss. A very common rock type is found especially in the oldest rocks of the Archaean age. Gneisses have been most commonly derived from the metamorphism of igneous rocks mostly granites but may have been formed from sedimentary rocks as well.

Gneiss is a coarse grained rock exhibiting gneissose structure. It is composed essentially of felspar, quartz and mafic minerals

such as mica or hornblende. Garnets are common accessory components. The successive mineral bands in a gneiss are generally of different composition, layers rich in quartz and felspar alternating with layers rich in mafic constituents.

Varieties are named after the chief mafic minerals as *hornblende gneiss* and *biotite gneiss.* If a gneiss is formed from the metamorphism of an igneous rock it is called *Ortho-gneiss.* If it results due to the metamorphism of a sedimentary rock it is known as *paragneiss.* *Augen gneiss* is a gneiss containing large lenticular crystals or aggregates of crystals, which are eye shaped.

Usually gneisses represent good engineering materials except for those with a super abundance of mica flakes.

Schist : This is largely composed of flaky minerals such as micas, chlorite, talc and hornblende which have a predominantly parallel arrangement called schistosity. The flakes or foliae into which the rock breaks, all have a similar mineral composition and the surfaces are lustrous. In addition to the flaky minerals there will generally be some quartz grains present. These, under the influence of stress, often become elongated and lie with their length in the surfaces of schistosity.

Mica schist is produced by the metamorpnism of original clay or shale. It is composed largely of mica (biotite and muscovite).

Chlorite schist is formed by the metamorphism of basic igneous rocks under conditions of high stress and low temperature and consists predominantly of chlorite with some quartz and a little garnet or magnetite.

Hornblende schist is made essentially of hornblende and is a metamorphic product of a basic rock like basalt or dolerite, the metamorphism occurring under conditions of moderate stress and moderate temperature.

Eclogite, a rock composed of pyroxene, garnet and quartz is formed from similar original material under conditions of low stress, high pressure and high temperature.

Talc schists and some *serpentine rocks* are formed due to stress metamorphism of ultrabasic rocks like peridotites

Slate. This is a low grade metamorphic rock and is dark coloured platy rock with extremely fine texture and easy cleavage. Because of this easy cleavage slate is split into very thin sheets and used as roofing material. It is essentially composed of chlorite, sericite and quartz. The presence of minerals like pyrite and marcasite are highly objectibnable.

Phyllite is formed due to action of heat along with stress during the metamorphism of argillaceous sediments. It differs from slate by its lustre, due to the presence of crystalline mica flakes.

Mica schist results due to intense metamorphism of argillaceous sediments. There is thus a gradation,

shale——slate——phyllite——mica schist,

which results from the stress metamorphism of material which was originally mud ending with a completely crystalline rock.

Quartzite. This is formed due to metamorphism of siliceous rocks like sandstones. It is chiefly composed of granular quartz. If iron impurities are present *banded hematite quartzite* results. It is a common and widely distributed rock. Its extreme hardness renders it unworkable in masonry but it serves as a good road metal.

Marble. This results from the metamorphism of limestones. It is composed mainly of interlocking grains of calcite. It is very dense and exhibits a wide variety of colours depending upon the impurities present. When the rock is broken, a highly brilliant surface is apparent because of the large size of the crystals normally found in marbles. Marble can be scratched with a knife and it easilv effervesces with dilute hydrochloric acid.

Dolomitic marble effervesces with HCl only if powdered.

In buildings marble is used for facing exterior and interior walls and floors. Some varieties are used for decorative purposes as they

take high polish. Some other varieties are used in the manufacture of cement, preparation of lime, as flux in metallurgical furnaces and in chemical industries.

QUESTIONS

Group-A

I Match the following :

1. Phaneric	a. Granite
2. Leucocratic	b. Composed entirely of Olivine
3. Gabbro	c. Hypabyssal Rock
4. Pebbles	d. Light coloured
5. Salt pepper pattern	e. Crystals visible to the naked eye
6. Dolerite	f. Coarse Sandstone
7. Stalactite	g. Organic deposit
8. Grit	h. Shale
9. Guano	i. Chemical deposit
10. Porphyritic	j. Plutonic equivalent of basalt
11. Compacted clay	k. Conglomerate
12. Dunite	l. Large crystals embedded in a groundmass of smaller grains

II. Select the best term to complete the following statements.

(1) The main mineral found in Limestone is :
a. Garnet b. Peat c. Calcite d. Limonite

(2) The rock made of cemented quartz grains is :
a. Conglomerate b. Clay c. Gabbro d. Sandstone

(3) Fossils may be found in :
a. Granite b. Obsidian c. Schist d. Limestone

(4) One of the typical monomineralic rock is:
a. Dolerite b. Dunite c. Diorite d. Diabase

(5) Basalt is the volcanic equivalent of :
a. Gabbro b. Arkose c. Gneiss d. Granite

III. Decide whether these statements are true or false. Reword the false statements to make them true.

(1) Conglomerate is a fine grained sedimentary rock.
(2) Fossils are often found in intrusive igneous rocks.
(3) Granites are usually leucocratic, in colour.
(4) Magma is nothing but a molten liquid underneath the earth's crust.
(5) Basalt resembles Dolerite to a great extent.

Group-B

I. (*a*) What are the three principal kinds of rocks?
(*b*) Explain the basis of their classification.
(*c*) Describe their chief characteristics with examples.

II. Give the differences between Plutonic and Volcanic rocks. State the mineral composition and textural features of the following rock types.
(a) Granite (b) Diorite (c) Andesite (d) Dolerite

III. Classify the secondary rocks and describe an example from each.

IV. Critically comment the following statements .

(*a*) Of the three classes of rocks, igneous rocks are the oldest.
(*b*) Many sedimentary rocks are fossiliferous.
(*c*) The banded or laminated character is the most striking Peculiarity of a metamorphic rock.

V. Describe the mineralogical composition, texture and economic importance of any three of the following rock types.

1. Pegmatite 2. Peridotite 3. Laterite 4. Marble 5. Syenite.

VI. Write an essay on metamorphism.

STRUCTURAL GEOLOGY

Structural Geology deals with the nature, properties, relations and positions of the component rock masses of the outer part of the earth. It includes the architecture of the outer shell of the earth. A knowledge of the different structural features of rocks commonly met with in the field is essential in carrying out successfully many engineering works such as construction of dams, tunnels, mountain roads, canals etc.

IGNEOUS ROCKS

FORMS OF IGNEOUS ROCKS

Variety	Example	Structure
Extrusive	Lavas	Glassy or finely crystalline
Intrusive—Major	Batholith and laccolith	Coarsely crystalline
Minor	Dykes and sills	Mainly fine grained

Extrusive Rocks

Volcanic neck (or pipe) is a rocky crag consisting of solidified lava which formerly filled the central opening of a volcano and has been left isolated when the remainder of the cone has been worn away by weathering and erosion.

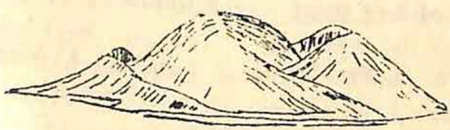


Fig. 36. Lava cones.

Lava Flows. The most common form of extrusive rocks is the lava flow. The form of a lava flow is determined by the fluidity

of the magma which in turn depends upon its chemical composition and the temperature during eruption. The igneous rocks are mainly of two types, acidic and basic. Acid lavas are highly viscous and they do not flow freely, but they get heaped up around the vent of eruption. They form what are known as *lava cones.*

Basic lavas are highly fluid and they flow over large areas, just as in the case of the Deccan Trap formation in the Indian region. Such lava flows are called *Sheets of Lava* or *Lava Sheets.*



Fig. 37. Lava sheets.

Block lava. Some lava flows get covered with a mass of rough, jagged, angular blocks of all dimensions when they are described as block lava.

Ropy lava. Very mobile lavas solidify with much smoother and highly glazed surface often exhibiting wrinkled, ropy or corded forms similar to those displayed by flowing pitch. These are known as ropy lava.

Block and ropy types of lava are best developed in basalts and may occur side by side in the same flow.

Pillow structure. Most of the basic lavas exhibit the appearance of a pile of small masses resembling pillows, bolsters, sacks and cushions. This is known as pillow structure. The interspaces of the pillows are filled sometimes with breccia cemented by secondary minerals.

Flow Structure. Lava flows differ slightly in composition, gas content, viscosity and degree of crystallisation during and immediately after the extrusion. During the process of flow the vesicles and bubble cavities are elongated in the direction of lava flow into parallel lenticles. This kind of structure is known as flow structure. Acid lavas and sub-acid lavas such as rhyolites and trachytes show perfect flow structures.

Intrusive Rocks

Batholith. This is an irregularly shaped mass of plutonic igneous rock. The name itself means depth-rock. Of deep-seated origin, it may now appear at the surface due to denudation and erosion and when it does so, being usually harder than the surrounding strata, it stands out in hills or ridges. It is characterised by steep sides and no known floor.

Stocks are irregular masses of batholithic habit of smaller dimensions than those above and *boss* is applied to those stocks in which the outcrop is approximately circular. Stocks and bosses are usually offshoots from a larger batholithic mass

The largest known igneous bodies of the world are among the batholiths and where exposed at the earth's surface they cover hundreds of square miles. Batholiths are found in regions of folded rocks, especially in the cores of mountain folds and generally possess an acidic (granitic) composition.

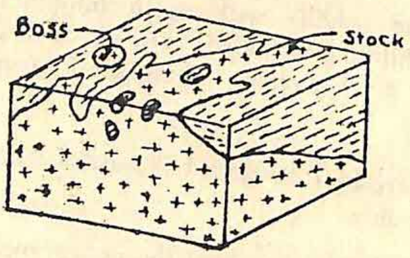
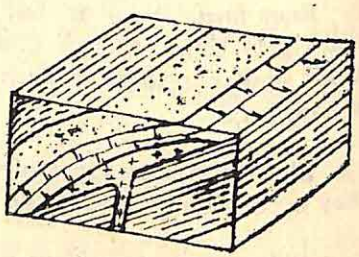


Fig. 38. Batholith.


Fig. 39. Laccolith.

Laccolith. A magma of considerable viscosity injected into stratified rocks does not spread very far, but tends to heap itself up about the orifice of eruption. Thus a bun shaped mass of igneous rock is formed which has a flat base and a domed top; the strata above it are lifted up in the form of an inverted bowl. This type of intrusion is described as laccolith. Laccoliths are occasionally circular or more often elliptical in ground plan according as the supply is from pure cylindrical *vent* or from an elongated fissure.

During the injection of laccolith and its stiffening due to cooling at the contacts, it may cause a steepening of the lateral margins of mass almost to verticality when it is termed *bysmalith.*

A somewhat similar intrusive form called *phacolith* has both roof and floor curved. This is due to the magma having been intruded into rocks which were already folded.

Lapolith. These are massive instrusions of basic rocks which are generally concordant, have a lenticular shape and are centrally sunken like a saucer or basin.

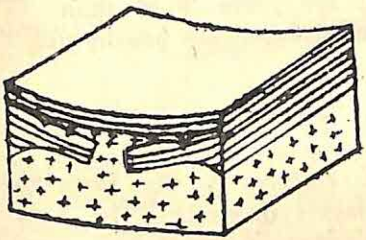


Fig. 40. Lapolith.

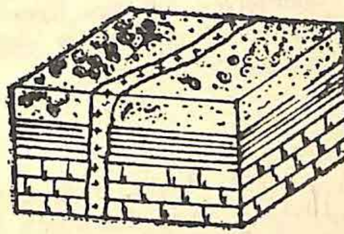


Fig. 41. Dyke.

Dykes. The intrusion of magma into more or less vertical fissures which cut across the bedding or other structures of the invaded rock, results in the formation of dykes. A dyke (*Scots*: dike—a wall of turf or stone), as the name indicates, is thus a narrow, elongated, parallel sided wall of igneous rock. The thickness may vary from an inch or two to many hundreds of feet, but the great majority of dykes are probably less than 10 feet thick. Similarly the length of a dyke may vary from a few yards to many miles. Dykes are frequently more resistant to erosion than the enclosing rocks and tend to project as walls at the surface. Dykes tend to occur as systems or swarms which are parallel to one direction or radial.

Sills are thin tabular sheets of magma which have penetrated along approximately horizontal bedding planes. They show parallel upper and lower margins for considerable distances; but as they thin out in distance the shape is flatly lenticular. The thickness may vary from a few inches to many hundreds of feet. Sills spread to a distance which is dependent on the hydrostatic force with which they were injected, their temperature, degree of fluidity and the weight of the block of strata which they have to lift in order to make room for themselves. Since basic magmas are more fluid than acid, the rocks composing the more extensive sills are usually dolerites and basalts.

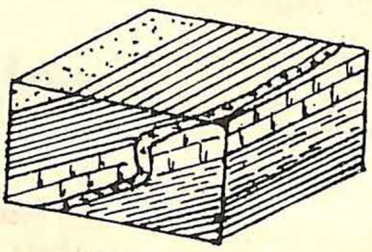


Fig. 42. Sill.

SEDIMENTARY ROCKS

One of the most characteristic features of the sedimentary rocks is their deposition in beds, layers or strata. The bedding or stratification is indicated by differences of composition, texture, hardness, cohesion or colour disposed in approximately parallel bands. This well known feature of sedimentary rocks is known as stratification. Stratification, otherwise obscure, is frequently brought out clearly by the weathering processes.

Over wide regions the stratified rocks appear to be lying in a general way in the horizontal position in which the beds were laid down and to have been raised to form land surfaces, without serious displacements; but in other places, notably in mountain regions, this is not the case. Here, on the other hand, we find the strata inclined often at high angles, thrown into folds, contorted, bent and often more or less broken. This deformation of strata results due to tectonic earth movements such as the mountain building, volcanic movements etc.

Sedimentary rocks exhibit certain special surfacial features such as current bedding or false bedding and ripple marks.

Current Bedding or *False Bedding* is a peculiar type of structure characteristic of sandstone and littoral or shallow water deposits. The layers are often inclined to one another at various angles due to changes or oscillations in the direction and strength of the agents of transport and deposition, i.e., water and wind. This irregularity is developed in even more striking fashion in sand dunes.

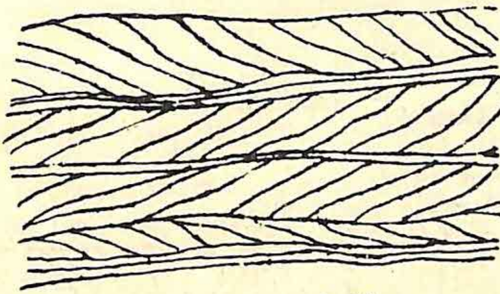


Fig. 43. Current bedding.

Ripple Marks. In shallow water, it is frequently noticed that the sand at the bottom has been thrown up into a series of small parallel ridges by the action of the waves. These are known as ripple marks. Ripple marks are produced by the oscillation of the water driven into movement by wind playing over its surface. Similarly we see various kinds of surfacial features on fine grained sedimentary rocks like sandstones and shales.

Examples. Wave marks near sea-shores, sun-cracks round the shores of inland seas and lakes, rain-prints and animal tracks on fine grained strata.

Concretionary Structures. They are usually externally smooth and compact, but ofter internally fissured, the fissures being sealed with some mineral which is frequently calcite. They occur as inclusions in sedimentary rocks and are rounded and nodular in form. Some occurrences are quite spherical, others flattened ovate, elongated, ring-shaped or compound, exhibiting odd and fantastic shapes, e.g., Phosphatic nodules.

Folds. Although the sedimentary rocks were deposited in a more or less horizontal position it is, nevertheless, of common occurrence to find them in tilted and disturbed position. This deformation of original strata is brought about by the compressive forces acting during the crustal earth movements. Owing to these disturbing forces massive sheets of strata are found inclined and bent into huge flexures or folds miles across. The variations in the nature of folding have given rise to different types of folds.

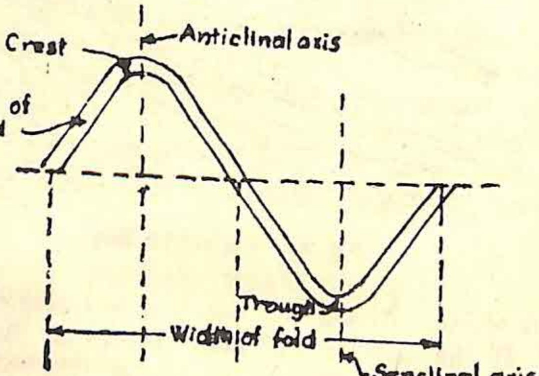


Fig. 44.

In a series of folds, it is evident that, like waves, they consist of alternate crests and troughs. The crests of the folds are termed '*anticlines*', while the troughs are usually called '*synclines*'. An anticline and a syncline constitute a fold. The *crest* is the highest part of the curve where the dip of the bed is reversed. The *limb* or *flank* of a fold is

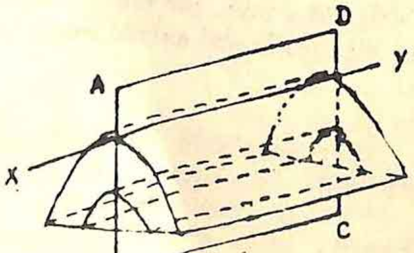


Fig. 45.

the sloping side from the crest to trough. The plane bisecting the vertical angle between equal slopes on either side of the crest line is known as the *axial plane*.

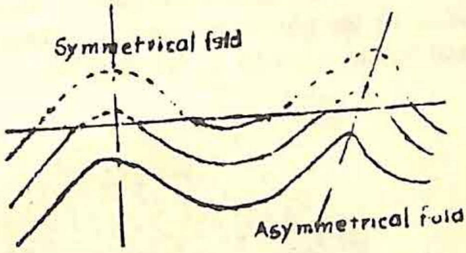


Fig. 46.

If the axial plane is vertical and the limbs are of equal inclination to it and of equal length, the fold is *symmetrical*.

If the limbs are unequally inclined to the axial plane or of unequal length the fold is *asymmetrical*.

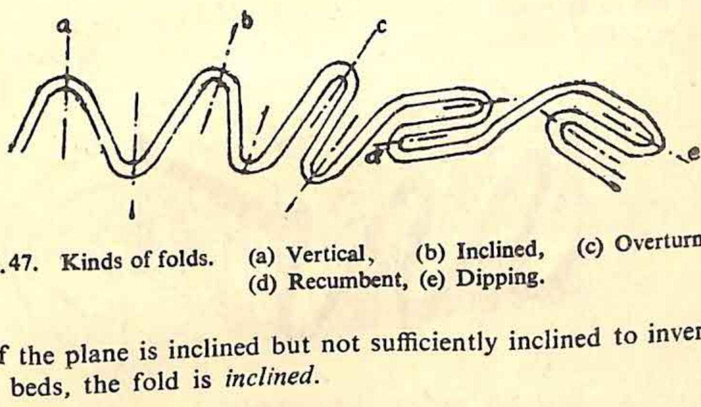


Fig. 47. Kinds of folds. (a) Vertical, (b) Inclined, (c) Overturned, (d) Recumbent, (e) Dipping.

If the plane is inclined but not sufficiently inclined to invert any other beds, the fold is *inclined*.

If the axial plane is vertical the fold is *vertical* or *upright*.

If the axial plane is sufficiently inclined to invert the stratigraphical order of any of the beds, the fold is *overturned* or *inverted* and when the plane is horizontal the fold is *recumbent*.

If the apex of the fold is depressed below the axis of the fold it is said to be *dipping*.

A *monocline* or *monoclinal fold* is inclined in one direction represented by the portion of the bed with a steeper dip connecting lower and higher segments of the same bed.

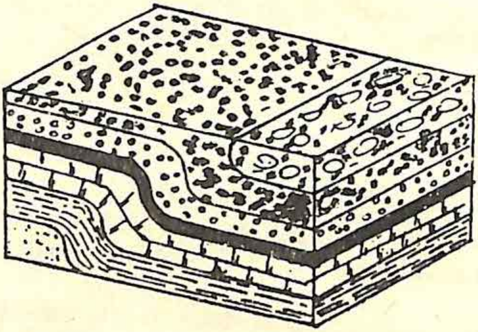


Fig.48. Monoclinal fold.

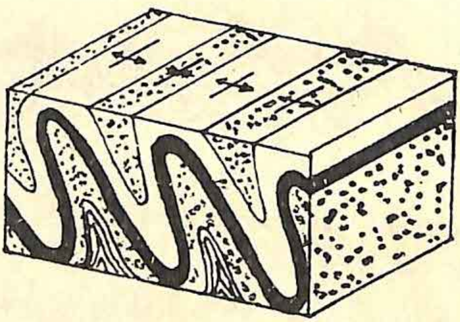


Fig. 49. Isoclinal fold.

An *isocline* or isoclinal fold is a repetition of the limbs of a succession of closed folds standing at the same inclination or overfold in which both limbs show the same amount of dip.

Parallel folds are a series of flexures or undulations in which the beds run in parallel sinuosities.

Pitch. The dip of crest line is sometimes called pitch.

Plunging or pitching folds. These folds have an inclined crest line which may dip below the other transgressive layers Fig.50(a).

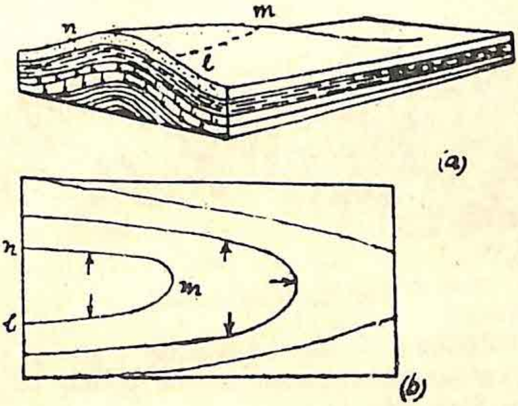
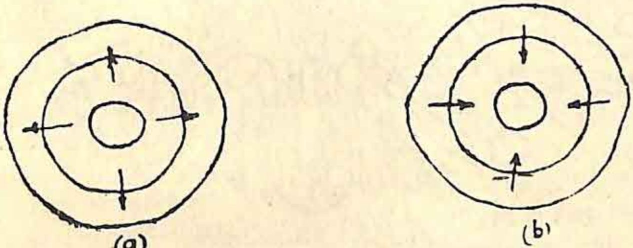


Fig. 50. Pitching fold.

On the map the pitching folds show that the two outcrops of the bedding surfaces of a stratum on a nearly flat surface converge and meet each other in the direction of the pitch Fig. 50(b).



(a) Dome. Fig. 51. (b) Basin.

If the strata are folded also in the axial plane of the folding they may form a *dome* or a *basin*. A *dome* is anticlinal in two vertical sections at right angles to each other whereas a basin is synclinal in two such sections. The former is also known as *quaquaversal* fold. Domes and basins are characterised by radial dips of the strata.

Anticlinorium and *synclinorium* are terms applied respectively to an anticline or a syncline when it is a composite fold. Anticlinoria

and synclinoria are good examples of large fold mountain areas, Alps and Himalayas. *Normal Anticlinorium* is fan shaped in

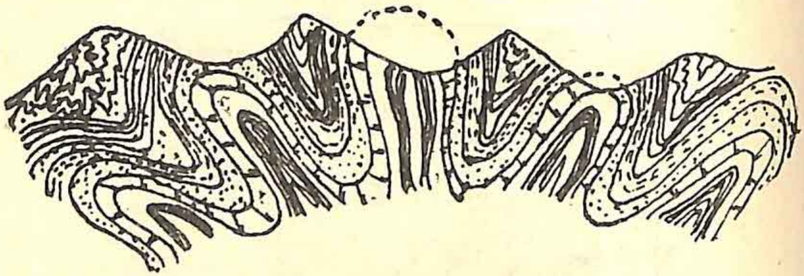


Fig. 52. Anticlinorium.

structure and here the folds dip towards the centre of the mountain massif. *Synclinorium* is common in the region of intense earth movements e.g. Alps, Himalayas.

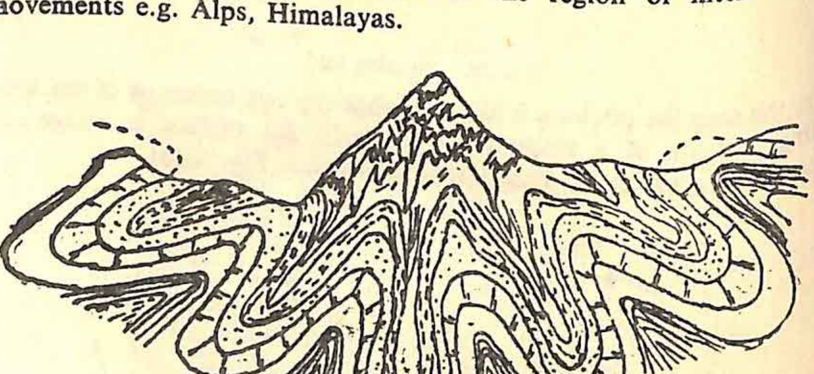


Fig. 53. Synclinorium.

Conformity and Unconformity. Strata deposited during a period of sedimentation are conformable or concordant, when the stratified deposits occur as regularly and continuously laid beds, a layer after layer, without any change in the general parallel arrangement. The structure then produced is known as conformability or conformity. When beds

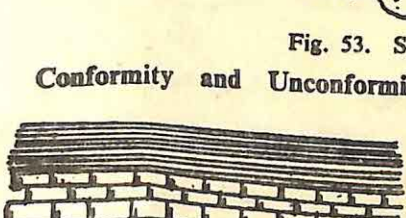


Fig. 54. Conformable beds.

after one period of sedimentation, have been lifted up, deformed, eroded and again submerged to serve as the floor for a new deposit, the new series of strata will be lying unconformably or discordantly upon the old series. Then the structure produced is known as unconformity. Unconformity indicates that there is no connection between the sedimentation of the first and the second period and that they were deposited in two independent seas or lakes, during two different periods.

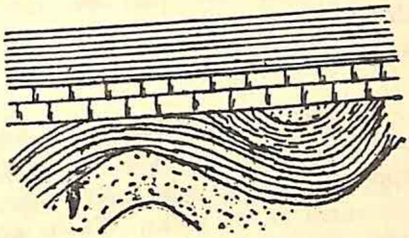


Fig. 55. Unconformable beds.

Overlap. When the upper beds of the sedimentary formation extend over a wider area than the lower beds of the same series,

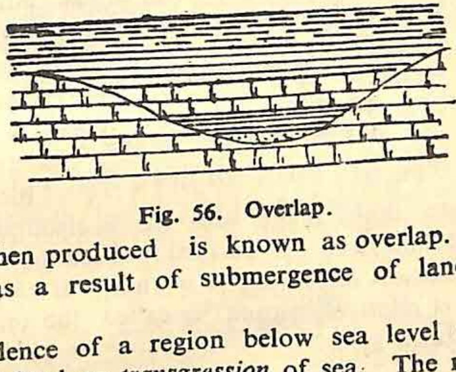


Fig. 56. Overlap.

the structure then produced is known as overlap. This structure is developed as a result of submergence of land or invasions of the sea.

The subsidence of a region below sea level is known as a *submergence* of land or *transgression* of sea. The retreat of sea is known as a marine *regression* or an *emergence* of a land.

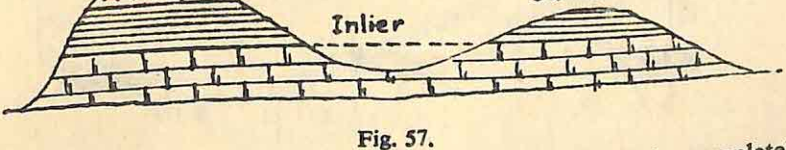


Fig. 57.

Outlier and Inlier. An outcrop of rock which is completely surrounded in plan by older rocks is called an outlier. The

converse of this is an inlier, *viz.*, an area of older rocks surrounded by newer. Inliers are often developed in valleys where streams have cut down and exposed locally the rocks which are below those forming the sides of the valley.

Faults. A rock series may be broken or faulted by the forces of the earth movements. A fault is a break, shear or fissure, on opposite sides of which there has been relative movement or displacement of the rocks. Faults are due to unequal compression or tension on adjacent parts of a formation. Other causes are withdrawal of foundation rock due to the leaching out of certain layers or the shifting of magmas and contractions due to the cooling of magmas.

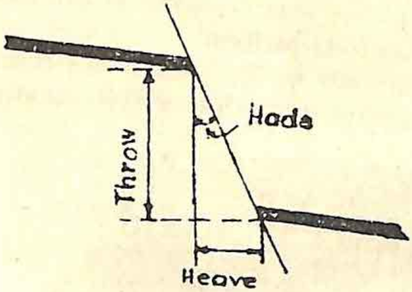


Fig. 58.

The fault occurs along a surface which usually approximates to a plane. The actual plane of fault and slipping along which the strata have given way is known as the *fault plane*. A fault plane has a direction and amount of inclination, the amount being the angle made with the horizontal. The general inclination of the fault from the vertical is called the *hade* of the fault. The amount of vertical displacement is known as *throw* of the fault. The side which is relatively raised is called the upthrow side, the other the downthrow side.

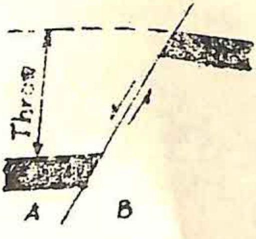


Fig. 59.
Normal fault.

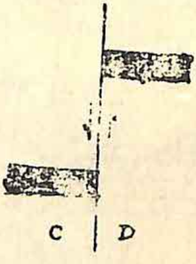


Fig. 60.
Vertical fault.



Fig. 61.
Reverse fault.

A fault is a *normal fault* when the fault plane is inclined to the downthrow side.

A fault is vertical when the fault plane is vertical.

A *reverse fault* is one where the fault plane is inclined to the upthrow side.

Thrust Faults are low angle reverse faults in which the dip may be only a few degrees while the length a few hundred miles and the horizontal displacement a few tens of miles. The movement is known as *over thrusting* or *under thrusting*.

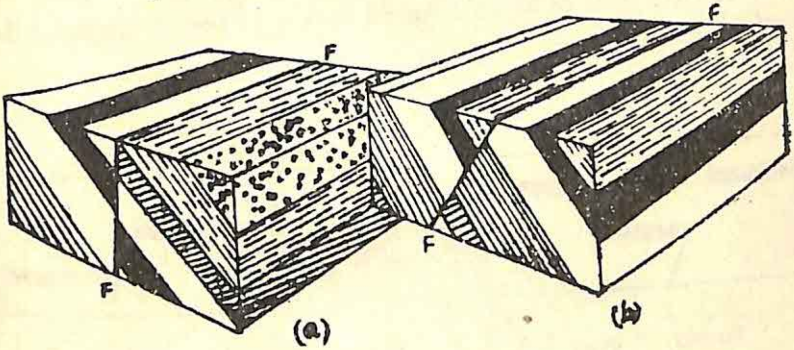


Fig. 62. Strike fault.

A fault is a *strike fault* when the strike of a fault plane approximates to the strike of the bedding and a *dip fault* when it approximates to the dip.

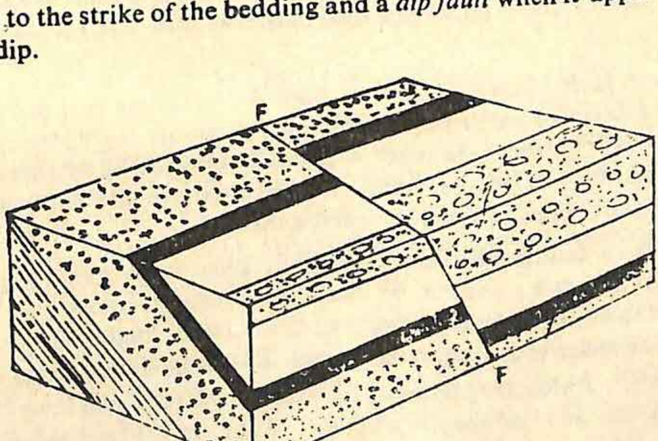


Fig. 63. Dip fault.

Step fault. A series of parallel faults which displace the separated blocks always in the same direction is called a step fault.

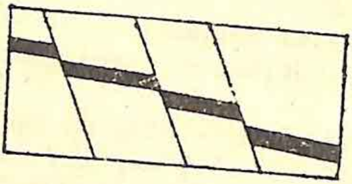


Fig. 64. Step fault.

A zone faulted by two series of step faults facing each other is called a *rift, graben* or *trough fault.* A central block on both sides of which adjacent beds have been faulted down is *horst.*

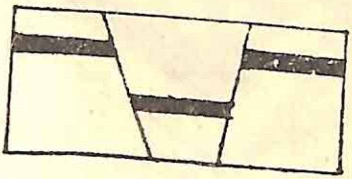


Fig. 65. Trough fault.

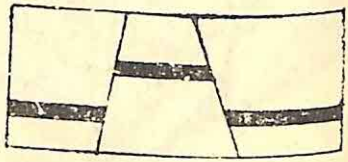


Fig. 66. Horst.

Slicken sides. In some places the rocks along a fault are polished due to movement. Such polished surfaces are known as slicken sides.

These fault planes remain as lines of weakness in the rocks of an area subject to earth movements and often act as "safety valves" for the relief of strain; the relief is generally effected by further sudden relative movements of the rocks on each side of the fault, thereby producing the phenomenon of earthquakes.

Lines of faulting therefore generally have to be avoided and no important structure should be built transversely across the line of strike of a fault. Among very ancient rocks faults may become "dead" or mineralized into veins and thus may be perfectly safe.

Joints. Joints are planes of division in the rock and may traverse both igneous and sedimentary rocks. They should not be confused with the faults or bedding planes. Along the planes of joints there is no displacement as in the case of faults. Joints are ordinarily smoother than the bedding planes.

The chief causes for the development of joints are as follows :

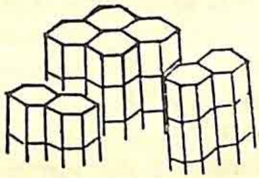


Fig. 67. Columnar joints.

1. The shrinking of igneous rocks on cooling develops characteristic types of joints. *Columnar* or *prismatic* joints are developed in basalt and other basic rocks and *mural jointing* in granites.

2. Joints may form due to pressure and when they are closely spaced the rock has *fracture cleavage.*

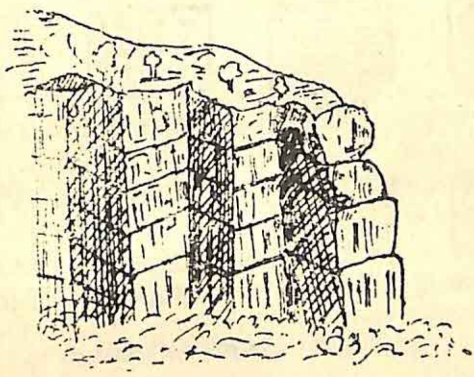


Fig. 68. Mural jointing.

In sedimentary rocks one set of joints is usually along the bedding planes while the other two are parallel to the dip and strike and are called *dip joints* and *strike joints* respectively. Joints which keep the same direction for long distances and run through a considerable thickness of beds are called *master joints.*

From the economic point of view, joints in rocks are planes of easier detachment of the rock. Compact, unstratified and uncleaved masses are difficult to mine while laminated or well cleaved rocks with many systems of joints are broken at much less expense.

Rift and Grain. These are directions in granitic rocks of comparatively easy splitting at right angles to one another, one horizontal and the other vertical, used by quarrymen in dressing the blocks of

small dimensions while mural jointing is used to procure large blocks. In the direction at right angles to both rift and grain the granite breaks with a rough irregular fracture.

STUDY OF GEOLOGICAL MAPS

A geological map shows the distribution of the various rocks or formations at the surface of the ground and also the geological features. The rock formations are indicated on a geological map by various colours or patterns, and the structures by different kinds of lines and conventional signs.

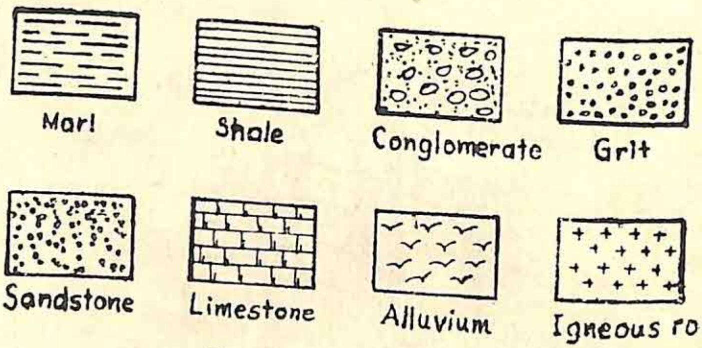


Fig. 69. Conventional signs.

A topographical map showing the surface feature of an area is used as a base map for plotting the geological formations of that area. A *contour* is a line drawn upon a map through points having the same altitude above mean sea level. Contours are drawn at some equal vertical distance which is called the *contour interval*.

A profile section shows the shape of the surface it would appear in vertical cross section. It consists of four lines—the profile line or the top line formed by the intersection of the vertical plane with the land surface, the base line or a horizontal line representing a convenient level below the lowest of the profile line and the two end 'ines drawn perpendicular to the base line. The position of profile section is marked on a map by a line of section.

Outcrop. When a bed of rock appears at the surface of the ground it is said to outcrop at that locality. If the rocks remain

always in the horizontal plane in which they were laid down, only the upper beds would ever be visible. Fortunately, this has rarely occurred and in most localities earth movements during and subsequent to the deposition of rocks have caused the strata to be inclined so that they outcrop at the surface in succession one after another. The form of the outcrop of a bed depends upon the direction and amount of its dip and the topography of the land surface. The angle at which they are inclined to the horizontal is called the angle of dip.

True dip. True dip or full dip is the maximum angle which an inclined bed makes with the horizontal. It is the direction in which water would flow if poured on the upper surface of the bed at the outcrop.

Srike. A horizontal line in the plane of surface of the bed is called a strike line. A strike line is a level line and can be imagined as a contour line for the surface of the bed. If the bed is uniformly inclined strike lines on it at equal vertical intervals will be parallel straight lines at constant distance apart. If the bed is not uniformly inclined, but folded or contorted the strike lines on it will bend and curve just as the contour lines do on an uneven ground surface. Strike lines or stratum contours are lines drawn upon a map joining all points on the surface of the bed having the same height. The points where a stratum contour intersects a ground contour of the same height, are the points at which the surface of the bed will outcrop at the ground surface. For the present however, we will consider only strata of uniform dip and our strike lines will be straight running in a direction at right angles to the direction of the true dip.

Apparent dip. The inclination of the bed to the horizontal in any direction other than the direction of the true dip will be less than the angle of true dip. It is called an apparent dip.

The angle of dip is defined in terms of the degrees from the horizontal or in terms of the angle, i.e., a dip of 1 in 5 means that two strike lines 100 feet vertically apart would be 500 feet horizontally apart, the tangent of the angle of dip being 1/5. Unless there is definite information to the contrary the term dip used without qualification should be taken as meaning true dip and not apparent dip.

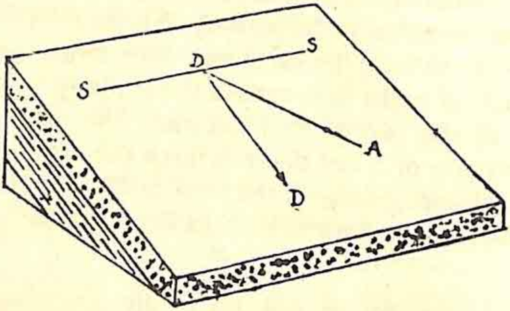


Fig. 70.

The figure represents a flat, uniform bed rock which is tilted out of the horizontal. The horizontal line SS on the sloping surface represents the strike of the bed. The line DD at right angles to SS is the direction of the maximum slope or dip. The inclination of a line such as DA gives what is called an apparent dip.

The following are some of the problems involving true and apparent dips :—

Problem 1. Given the amount and direction of true dip; to determine the apparent dip in any direction.

Example. A coal seam dips at the rate of 1 in 5 in a direction due south. Find its apparent dip in the direction S 60° E.

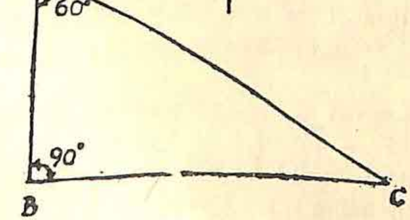


Fig. 71.

Method. Draw the north direction line. Draw AB 5 units long in the dip direction. BC drawn perpendicular to AB gives the strike direction. Draw AC making 60° with AB to cut BC at C. Measure AC. AC is found to be 10 units and therefore apparent dip in the direction AC is 1 in 10

Proof. Since AB is 5 units long B is 1 unit below A. Since BC is the strike line C is at the same level as B, i.e., C is 1 unit below A. AC is 10 units long. Hence apparent dip along AC is 1 in 10.

Problem 2. Given the amount and direction of true dip; to determine the direction of any given angle of apparent dip.

Example. A sandstone bed dips at the rate of 1 in 4 in a direction N 45° W. Determine the direction in which the dip of the strata is 1 in 8.

Method. Draw the north direction line. Draw AB 4 units long in the direction N 45° W. Draw CD perpendicular to AB. CD is the strike direction. With A as centre and 8 units as radius strike

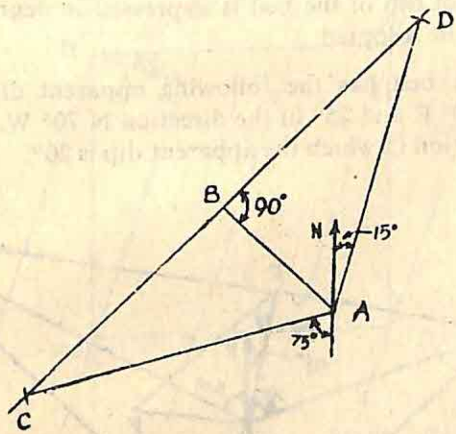


Fig. 72.

off arcs to cut the strike line at C and D. Join AC and AD. Measure ∠ABC and ∠BAD. Both are equal to 60°. Therefore the directions in which the bed dips at rate of 1 in 8 are S 75° W and N 15° E.

Problem 3. Given the rates and directions of two apparent dips; to determine the true dip.

Example. A bed has the following apparent dips, 1 in 7 in the direction N 50° E and 1 in 5 in the direction N 35° E. Find its true dip.

Method. Draw the north direction line. Draw AB 7 units in the direction N 50° E and AC 5 units long in the direction N 35° E. BC is the strike direction. Draw AD perpendicular to BC through A. AD is 3.5 units and angle NAD is 11°. Hence true dip is 1 in 3.5 in the direction N 11° W.

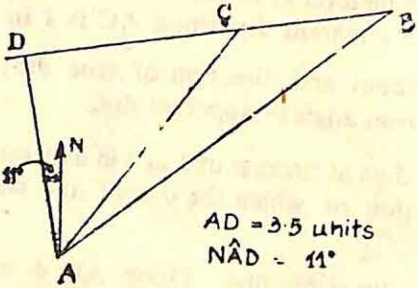


Fig. 73.

If the angle of dip of the bed is expressed in degrees the following method may be adopted.

Example. A bed has the following apparent dips, 15° in the direction of N 60° E and 25° in the direction N 70° W. Find its true dip and the direction in which the apparent dip is 20°.

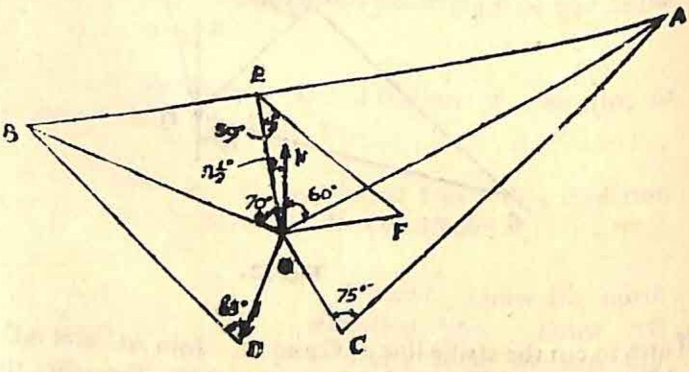


Fig. 74.

Method. Draw OA and OB in the directions N 60° E and N 70° W respectively. OC and OD are perpendiculars to OA and OB respectively and one unit long. Draw CA making 90—15=75° with CO, cutting OA at A. Draw DB making 90—25=65° with DO, cutting OB at B. Since A and B are at the same level AB is the strike

line for the bed. Draw OE perpendicular to AB. Draw OF perpendicular to OE and one unit long. Join EF.

Amount of dip=∠FEO=39°.

∠NOE=11½°, i.e. dip direction=N 11½° W.

Three point problem. A, B, C and D are 4 stations at the corners of a square of side 3000 feet on level ground. B is due west of A and C is due south of B. Bore holes at A, B and C meet with a coal seam at depths of 500 ft., 200 ft. and 300 ft. respectively. Find the dip and strike of the seam. At what depth will the seam be met with at D.

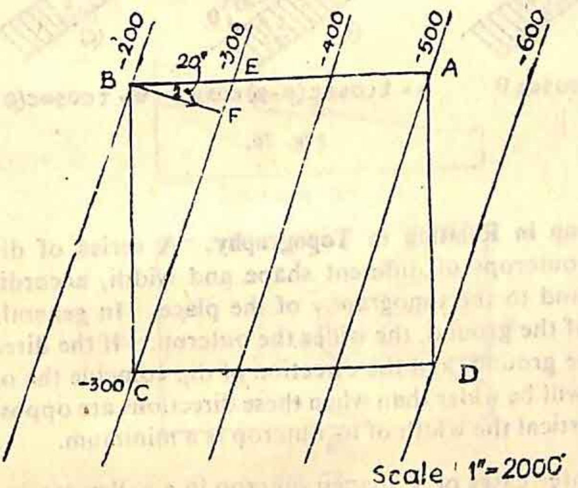


Fig. 75.

Method. Construct the square ABCD to a suitable scale. AB, the line joining the highest and the lowest levels of the bed is divided into 3 equal parts (3 being the difference in level between A and B divided by the contour interval which is here assumed to be 100). One of the points, E thus obtained has the same altitude as C and the line CE is therefore the strike line of the bed. Draw other parallels to CE through the points of division of AB and number them. Draw other parallels as necessary with the same spacing for values outside the range from A to B so that a strike line passes through the station

D. The value of the stratum contour that passes through D is 600. Therefore the depth at which the coal seam will be met with at D is 600 feet. To find amount and direction of dip draw BF perpendicular to CE. Measure BF and ∠EBF. If θ is amount of dip

$\tan\theta=\frac{100}{BF}=\frac{100}{840}$ Therefore $\theta=7$

∠EBF=20° i.e. Dip direction is inclined to AB at 20°.

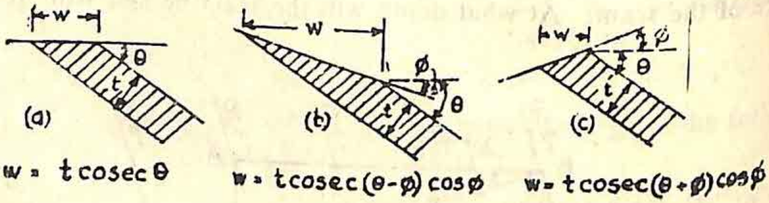


Fig. 76.

Outcrop in Relation to Topography. A series of dipping beds will have outcrops of different shape and width, according to their thickness and to the topography of the place. In general, the flatter the slope of the ground, the wider the outcrop. If the direction of the slope of the ground, and the direction of dip coincide the outcrop of a given bed will be wider than when these directions are opposed When a bed is vertical the width of its outcrop is a minimum.

The three cases of V shaped outcrop in a valley are as follows :—

(a) When beds dip in the direction opposite to the fall of the valley V points *up* the valley.

(b) When beds dip in the same direction as the fall of the valley and at a greater angle V points *down* the valley.

(c) When beds dip in the same directi n as the fall of the valley and at a smaller angle V points up the valley and is longer than in case (a).

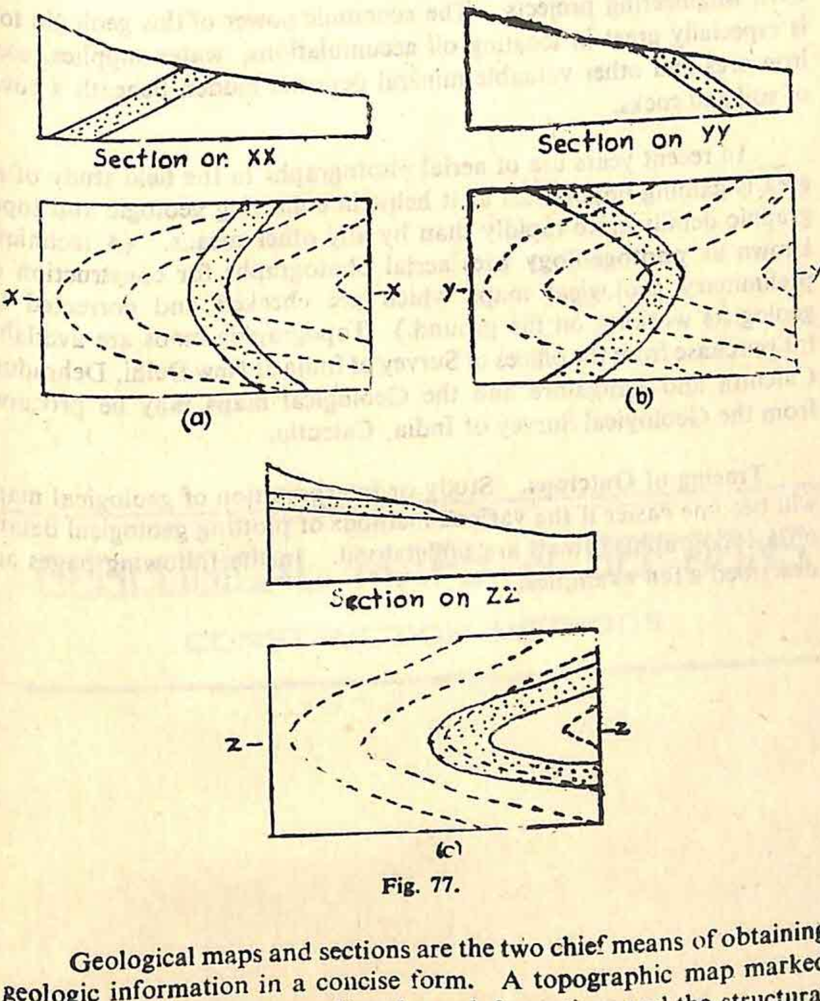


Fig. 77.

Geological maps and sections are the two chief means of obtaining geologic information in a concise form. A topographic map marked with additional details regarding the rock formations and the structural features like strike and dip of the beds, faults, folds etc., constitutes the geological map. Topographic map by itself may also convey a certain amount of geologic information as the topography tends to reflect the structure and composition of the underlying rocks. A geological section represents the way the rocks would appear on the side of a trench cut vertically into the land surface. Geological sections are commonly used along with geological maps in all economic applications of geology; for example, mineral prospecting, mining and

Civil Engineering projects. The economic power of this geologic tool is especially great in locating oil accumulations, water supplies, coal, iron ores and other valuable mineral deposits hidden beneath a cover of soil and rocks.

In recent years use of aerial photographs in the field study of an area is gaining importance as it helps in collecting geologic and topographic details more rapidly than by any other means. (A technique known as photogeology uses aerial photographs for construction of preliminary geological maps which are checked and corrected by geologists working on the ground.) Topographic maps are available for purchase from the offices of Survey of India at New Delhi, Dehradun, Calcutta and Bangalore and the Geological maps may be procured from the Geological Survey of India, Calcutta.

Tracing of Outcrops. Study or interpretation of geological maps will become easier if the various methods of plotting geological details on a topographical map are understood. In the following pages are described a few examples.

GEOLOGICAL MAPS & SECTIONS

CONSTRUCTION METHODS

Problem 1. **Given** topographic contours of the area and details of outcrop at the minimum necessary number of points, to trace the beds.

Example. The lower trace of a limestone bed 100 feet thick is given. Mark the underlying shale, limestone and the overlying conglomerate.

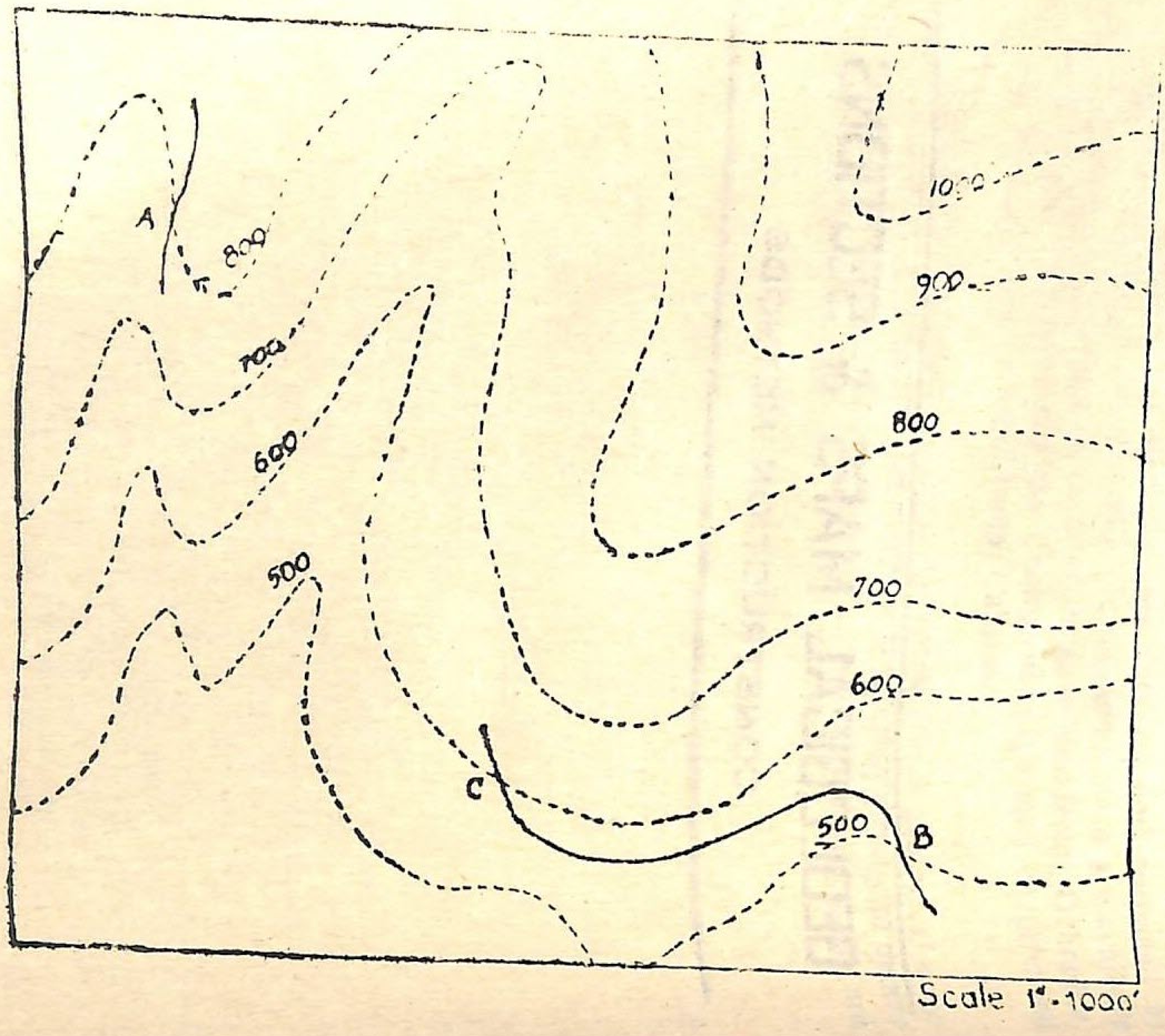
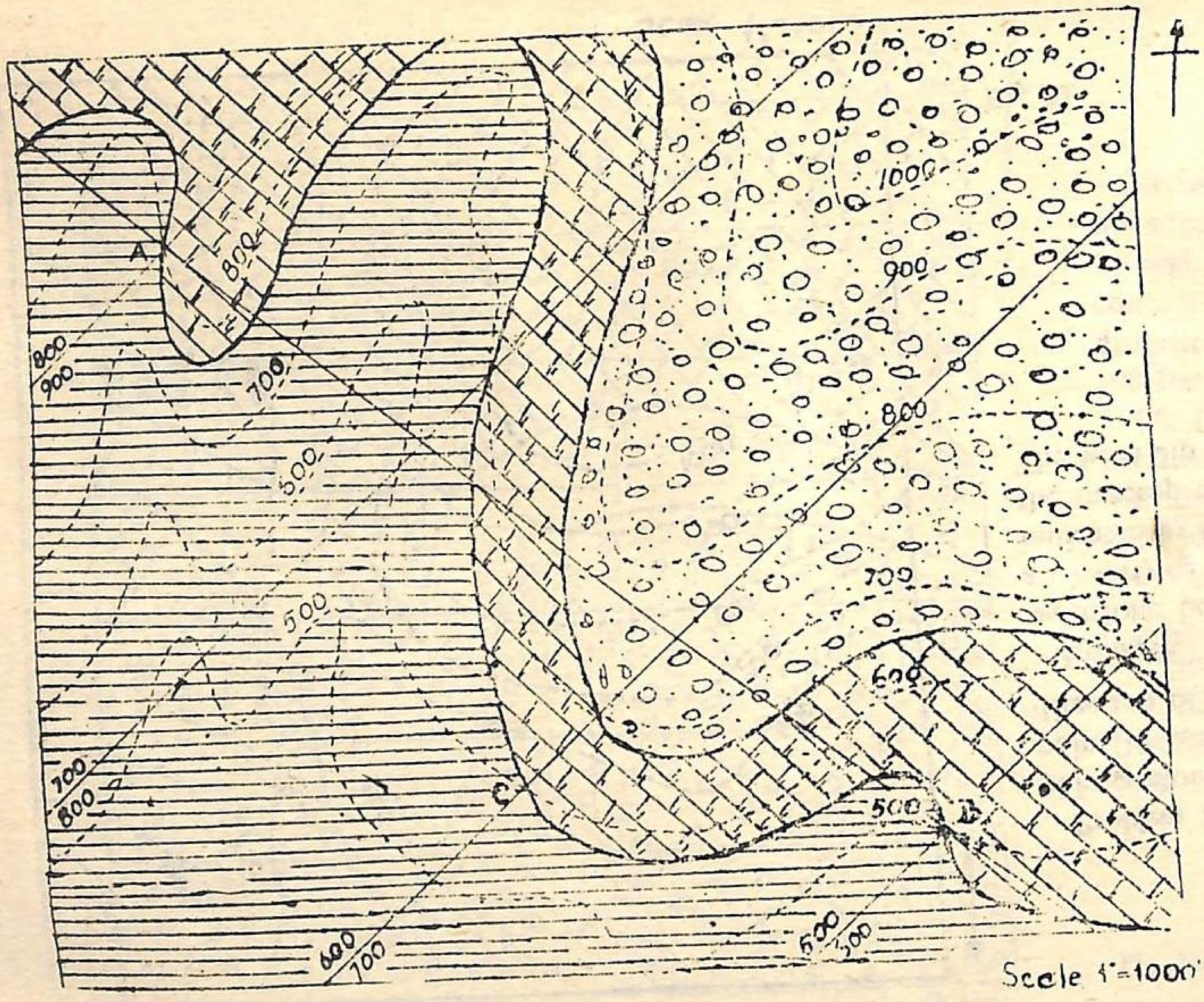


Fig. 78.



Method. The stratum contours are obtained in the same manner as adopted in the three point problem above.

Having drawn stratum contours, the required outcrop is obtained by joining the points of intersection of equal topographic and stratum contours.

To draw the outcrop of the upper trace of the limestone add the thickness 100 feet of the bed to the value of each stratum contour and with the new values obtain new intersections with the topographic contours. Through these points draw the outcrop. The underlying shale and overlying. conglomerate are shown.

Fig. 79.

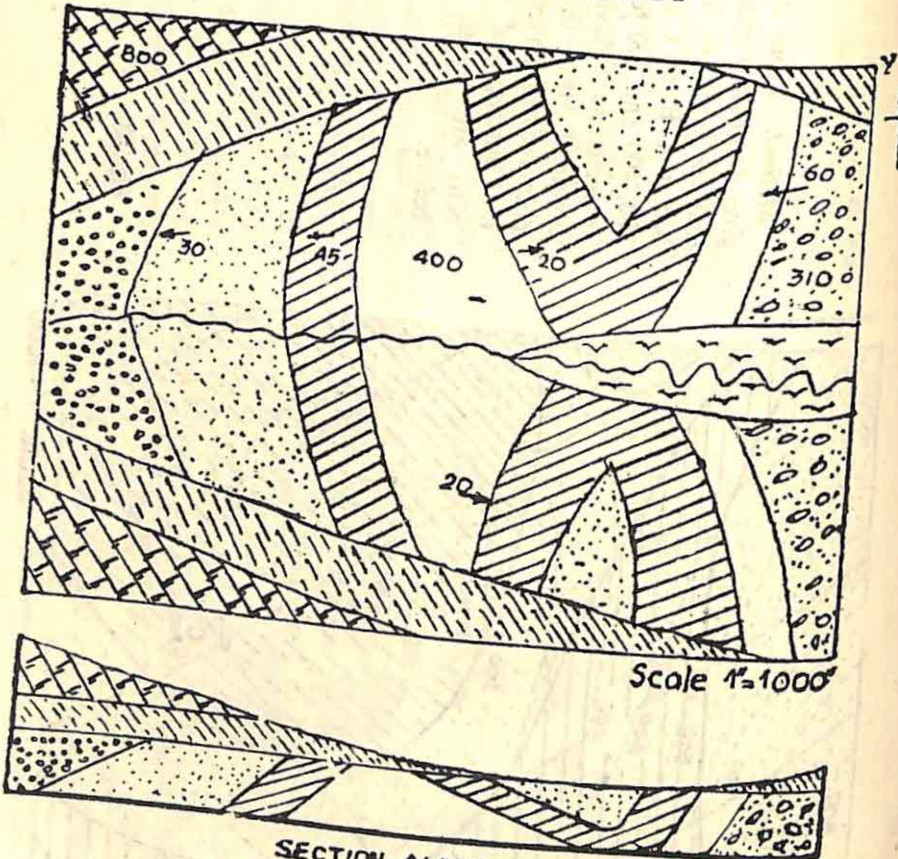


Fig. 84.

The map given above represents a region of folded beds with unconformable beds overlying them. The folded nature of the beds could be inferred from the dip of the beds as indicated by the arrows on the map. The section is taken along the northern edge of the map.

When drawing the section across the unconformity, the position of the older beds below the unconformable junction is deduced since they are not visible at the surface. This is done by working out the structure of the older series where they are exposed at the surface, and then producing the strike lines for this structure to the line of section.

QUESTIONS

I. What are the most important intrusive igneous forms? Explain with neat sketches.

II. Give a detailed account of the surfacial features of the sedimentary rocks.

III. What are the different kinds of folds? How will you recognize a fold in the field, and in the geological Map?

IV. Explain the following structural features with neat sketches.
(a) Anticlinorium (b) Unconformity (c) Horst
(d) Overlap (e) Pitching fold

V. How will you distinguish the following groups of features.
(1) Dip and strike, (2) Anticlinal fold and synclinal fold, (3) Outlier and Inlier (4) Dip fault and strike fault (5) Fault and joint.

VI. A sandstone bed has a true dip of 26° in the direction N 64° E. Calculate:—
(a) the apparant dip in the NNE direction
(b) the direction of dip for an apparent dip of 8°

VII. A Limestone bed dips at the rate of 1 in 6 in the direction N 40° W. Find the direction in which the apparent dip of the strata is 1 in 9.

VIII. A coal seam occurs at points A, B, and C which form a triangle, whose sides are AB=1500′, BC=2250′ respectively. B is NE of A and C is SE of B. The level of the coal seam is 700 feet above datum at A, 850 feet at B, and 350 feet at C. Find the dip and strike of the coal seam.

IX. A coal bed with 300 feet vertical thickness outcrops on a level surface. The base is seen at the station X while its top outcrops at station Y. The distance between XY is 600 feet. Find the dip along XY by both construction and calculation methods.

X. The upper trace of a sandstone bed dipping 1 in 8 due East is found at a point 'K' 4000 feet above datum. The lower trace of the same bed is found at point 'L' 3000 feet high situated at a horizontal distance of 5000 feet due west of K. Find the vertical thickness of the bed.

CHAPTER VI

INDIAN STRATIGRAPHY

Introduction. Study of stratified rock formations and the rocks forming their basement form the subject of the Historical Geology or Stratigraphy. The study of rock formations reveals the geographical and climatic conditions under which it came into existence. Built up of innumerable details, historical geology records the rise and fall of land, the invasion and retreat of seas, the growth of the deltas and coral reefs, the eruption of volcanoes and the changes between the tropical and glacial climates. Through all these changes of scene, it unfolds the development of life with culmination at last in man.

'THE PAGEANT OF PAST LIFE ON EARTH IS A STORY BY ITSELF'

Palaeontology is the study of ancient life as revealed in rock beds. From the record of life on rocks in the form of remains, casts, moulds, impressions of the ancient animals and plants which are called 'Fossils' (Fossil in Latin means something that has been dug up), we are able to gather information regarding the spectacular and fantastic variety of fauna and flora of the past periods of the earth's history. A few examples are described below :—

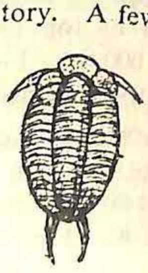


Fig. 85.Trilobite.

Trilobite. These were the most important animals that lived in the sea in Cambrian times about 400,000,000 years ago. Many of them were one to three inches long and a few one to two feet long. They had a protective shell which was divided into three parts. Hence the name Trilobite.

Dinosaur. These animals dominated the world during the Mesozoic era from about 200,000,000 to about 70,000,000 years ago. These are described as terrible lizards and giant reptiles. One of the most famous dinosaurs was Brontasaurus or thunder lizard which made the earth tremble as it moved along with its weight of 35 to 40 tons.



Fig. 86. Dinosaur.



Fig. 87. Archaeopteryx.

Archaeopteryx. It was an ancient bird with clawed fingers and teeth and of the size of a crow with a long tail feather. This existed in Jurassic period. It represents Nature's first attempt in aviation.

Mammoth. This huge animal, a predecessor to the elephant flourished during the ice-age one million years ago. Primitive men had to fight this monster and they used to trap them in oversized pits to attack them. Well preserved mammoth fossils have been found in Alaska. Indiana and Siberia.



Fig. 88. Mammoth.

To classify and correlate all the rock formations, is by no means an easy task. The principle of identifying the ages of strata by their fossils, has now been applied all over the world. The long sequence of formations which record the successive stages of earth's history can be divided into convenient divisions. The major groups are divided into systems, each system into series, each series into stages and each stage into zones.

The classes of terms used are one for division of time and the other for strata accumulated during those times.

TIME TERMS	STRATA TERMS
Era	Group
Period	System
Epoch	Series
Age	Stage or formation

GEOLOGICAL TIME CHART

Era	Period	Epoch	Distinctive features
Kainozoic (55 million years)	Tertiary	Recent Pleistocene Pliocene Miocene Oligocene Eocene	Supremacy of Man. The age of mammals, toothless birds and flowering plants.
Mesozoic (120 million years)	Cretaceous Jurassic Triassic		Age of reptiles and birds.
Upper Palaeozoic (160 million years)	Permian Carboniferous Devonian		Luxuriant vegetation.
Lower Palaeozoic (150 million years)	Silurian Ordovician Cambrian		Early life represented by marine fauna.
Azoic (1500 million years)	Pre-cambrian Archaean		Absence of life.

Physiography. India can be divided into three distinct units.

The first is the triangular plateau or peninsular shield. (Shield is a term used for geologically very old and stable parts of the crust of the earth).

The second division comprises the Indo-Gangetic alluvial plains.

The third is the mountainous region of the Himalayas known as the extra-peninsular region.

These three divisions exhibit marked contrast in physical features, stratigraphy and structure, ,and it appears to us that in many respects the physiography of India is an expression of its geological structure and history.

THE ARCHAEAN SYSTEM

Introduction. This formation is the oldest and forms the basement of all the sedimentary systems. Because of this and their complex constitution they are referred to as the *basement complex, gneissic complex* or *fundamental gneiss*. As these Archaean rocks are devoid of fossils, they are referred to as the azoic group of rocks. The rocks of this formation occur in the core of all the mountains which have been highly compressed and metamorphosed. In some regions these Archaeans are intruded by younger rocks which are of igneous origin.

With the Archaeans are included certain sedimentary rocks or mixture of sediments and igneous rocks which occur in compressed and partly buried synclinoria. These are included under the *Dharwar System* named after the district of Dharwar in Karnataka. The division of the Archaean group into Archaean system and Dharwar system, should not be carried to the extent of describing each as a separate unit since the two are very closely associated.

Distribution. The Archaeans occupy about two-thirds of peninsular India and a greater part of the Island of Ceylon. They stretch continuously from Kanyakumari to Madhya Pradesh and Bihar and continue apparently underneath the Ganges alluvium into the Assam plateau; the Mysore area is connected with that of Gujarat and Rajasthan beneath the Deccan traps. This vast stretch includes part of the states of Tamil Nadu, Kerala, Andhra Pradesh, Orissa, Bihar, Assam, Mysore, Western India and Rajasthan.

In the extra-peninsular area, the Archaeans are found in the lesser Himalayas.

Composition. The most common Archaean rock is gneiss. Associated with the Archaean gneisses, granites and schists occur some interesting rock types which are as follows :—

Nepheline Syenite occurs in Coimbatore, Vizagapatnam, Kisnengarh in Rajasthan and Junagadh in Kathiawar. These form a group of intermediate plutonic rocks. Among their normal essential minerals are found calcite and graphite in a quite fresh state.

Corundum Syenite occurs in the Coimbatore district in Sivamalai series.

Sivamalai series constitute six or seven small hillocks stretching in W–NW–direction near Sivamalai (45 miles from the town of Coimbatore) in the Coimbatore district. The chief rock types are nepheline syenite, corundum syenite and augite syenite. Common accessory minerals found in these rocks are graphite, biotite, magnetite, zircon, spinel and chrysoberyl. Some of the alkali syenites are very beautiful in appearance as they are composed of shimmering blue felspars—anorthoclase. This variety is similar to larvikite which is extensively used for shop fronts in European countries. The corundum of this area is collected by the village folk. Aquamarine (gemstone) is occasionally obtained from these rocks.

Charnockite occurs in Tamil Nadu, Mysore and Bengal. These were originally named as the *mountain gneiss* or *Nilgiri gneiss* by W. King as they constitute the Nilgiris and other hills in South India. They comprise a whole series of rocks ranging in composition from acidic to ultrabasic, the intermediate types being the most common. This has been named as charnockite by Sir T. H. Holland after Job Charnock, the founder of Calcutta, whose tombstone is made of this rock. The rocks are all characterised by the presence of orthorhombic pyroxene hypersthene.

Pegmatites. These coarse grained igneous rocks are widely distributed in the Archaean Complex in India. They occur chiefly as veins and dykes intersecting the older rocks. The acid granite pegmatites sometimes attain large dimensions. Pegmatite occurrences in Nellore, Bihar and Rajasthan have been found to contain many rare earth minerals and mica deposits of economic importance.

Peridotites and dunites. These ultrabasic rocks, though not widely spread, are of importance because of their association with

minerals of economic uses. They are the sources of chromite, magnesite and serpentine in India.

Among the well known occurrences are magnesite deposits of Salem, magnesite and chromite deposits of Mysore and chromite deposits of Singhbum in Bihar and Kashmir.

Gondite is a rock composed essentially of quartz and spessartite with varying amounts of manganese pyroxenes and amphiboles. It is formed due to metamorphism of manganiferous sediments and is often associated with manganese ores. These rocks are found in Bombay, Maharashtra and Madhya Pradesh.

Kodurite is another type of rock found in association with manganese ores. This rock is characterised by the presence of manganese silicates like rhodonite and spessartite. These rocks are found in Ganjam and Vizagapatnam districts of the Andhra Pradesh.

Khondalite is found in association with charnockites. It is essentially composed of quartz, sillimanite, garnet and felspar. These rocks may be called garnet sillimanite schists. Graphite occurs frequently in association with these rocks. These are found in Orissa.

Besides the various rock types described above the other less common varieties are quartz schist with iron ores, quartzite, phyllites, granulites and crystalline limestones.

Economic Importance. The Dharwarian rocks and the associated gneisses constitute the most important mineral bearing formation of India. They contain a large variety of useful metallic ores, industrial minerals and rocks, such as the iron ores of Bihar, Orissa, Madhya Pradesh and South India; the gold of Mysore, Hyderabad and Chota Nagpur; the copper ores of Nellore, Bihar and Rajasthan the chromite of Bihar and Mysore; the many non-metallic minerals used as abrasives, refractories, pigments, ceramic materials, gems and building and ornamental stones. The chief occurrences are described in the following paragraphs.

Gold occurs in quartz veins of several bands of the Dharwarian rocks of Mysore, Hyderabad, Anantapur, Wyanad in Malabar and Bihar of which Mysore occurrence is the most important one. In Mysore gold occurs in the Kolar area where there are four mines, viz., Mysore, Champion Reef, Ooregaum and Nandidurg.

Copper ores are found only in few localities, e.g., Singhbhum district in Bihar, Rajasthan, Nellore, Jubbalpore, and South Arcot District in Tamil Nadu. Chief ores are chalcopyrite and malachite.

Chromite is found in association with ultrabasic rocks, e.g., Mysore, Salem, Bihar and Orissa, of which Mysore and Bihar are of economic importance.

Iron Ores. Rich and extensive deposits containing over 60% iron occur in Bihar, Orissa, Madhya Pradesh, Mysore, Salem and Goa. The chief ores are hematite and magnetite.

Manganese is found in Bombay, Rajasthan, Madhya Pradesh, Maharashtra and Ganjam and Vizagpatnam in Andhra. The lateroid deposits of manganese occur in Bellary, Mysore and Jubbalpore. Chief ores are braunite, psilomelane, pyrolusite.

Lead Ores. Veins of galena are seen at Mewar and Jaipur and also in the states of Bihar and Madhya Pradesh, but they are thin and not of economic importance.

Titanium. Chief source is titaniferous magnetite which occurs in Bihar and Rajasthan. Another important occurrence is the coastal sands of Travancore containing rutile and ilmenite.

Tin and Tungsten. Cassiterite and wolframite minerals occur in small quantities in Hazaribagh district of Bihar and Bhilwara district of Rajasthan. Detailed prospecting in these areas may yield good result.

Nickel and *Cobalt* are found in Rajasthan. These are used for the manufacture of sulphates and making a blue enamel employed in jewellery.

Bauxite occurs in Shevaroy hills near Salem in Tamil Nadu.

Molybdenite occurs in Palani hills in Tamil Nadu, Godavari district and Rajasthan.

Stibnite occurs in Jubbalpore and Mysore.

Columbite and *Tantalite* occur in Bihar.

Vanadium occurs in Orissa. Chief source is vanadiferous magnetite.

Uranium. Pitchblende and uranium ochre occur in Bihar.

Thorium. Monazite sand of Travancore is the chief source of his element.

Mica occurs in the form of books in the pegmatite dykes of Bihar, Nellore and Rajasthan. Ruby mica of Bihar is of the best quality and is in much demand for use in the electrical industry. Phlogopite occurs in Travancore.

Vermiculite. It occurs as altered products of Micas in the following places. Srikakulam district in Andhra Pradesh, Hazaribagh district in Bihar, Hassan and Tumkur districts in Mysore and North Arcot district in Tamil Nadu. In recent days it is used in the manufacture of lightweight concrete.

Asbestos (Tremolite variety) occurs in Bihar, Rajasthan, Madhya Pradesh, Mysore.

Corundum occurs in Coimbatore, Salem, Assam and Rajasthan.

Apatite is found in Bihar and Andhra.

Garnet is widely distributed in crystalline rocks. It also occurs as coastal sands in Tirunelveli, Kanyakumari and Travancore.

Graphite occurs in Orissa, Vizagapatnam, Tirunelveli, Travancore and Hyderabad.

Magnesite is found in association with ultrabasic rocks of Salem and Mysore. Best known occurrence is Chalk hills near Salem.

Kyanite is found in Mysore, Nellore, Bihar and Orissa.

Steatite and *Talc schist* occur in Jubbalpore, Jaipur, Mysore and Tamil Nadu.

Fluorite. Important deposits occur in Madhya Pradesh, Rajasthan and Gujarat of which Fluorite deposit that occurs in the Baroda District of Gujarat is considered to be the biggest deposit in India.

Gemstones. A large number and variety of precious and semi-precious stones are found in the Archaeans. Amongst them are sapphires from Kashmir; aquamarine from Rajasthan, Tamil Nadu and Kashmir; Chrysoberyl from Coimbatore and Rajasthan; garnet from Jaipur, Mewar and other states in Rajasthan; tourmaline from Kashmir.

Building and Ornamental stones. The Archaean gneisses and granites form an inexhaustible source of excellent building stones. Most of the temples and public edifices in India (South India) have

used gneisses and granites in their construction. The temples of Seven Pagodas at Mahabalipuram near Madras are hewn out of charnockites, while those of Madurai, Tiruchirapalli and other places are built of gneisses and granites.

Many of the crystalline limestones in the Dharwarians are rocks of high decorative value. The Makrana marble of Rajasthan has been used in the construction of Taj Mahal and other buildings on North India. Several of the white, grey and coloured marbles of Rajasthan and Madhya Pradesh have occasionally been used for building purposes.

THE PRECAMBRIAN SYSTEM

The rock formations of the Precambrian age in Indian Geology are known as Purana Group of rocks. They are divided into two systems, Cuddapahs and Vindhyans. In early periods they were referred to as diamond-sandstone formations because of their association with diamonds.

THE CUDDAPAH SYSTEM

Introduction. Overlying the denuded edges of the Archaean rocks after a period of unconformity is found the Cuddapah system of rocks. It is named after the Cuddapah district in the Andhra state where it is well developed.

Composition. The Cuddapah rocks are mostly of sedimentary origin. The chief rock types are shales, slates, sandstones, quartzites and limestones. They are entirely unfossiliferous and the absence of fossils may be attributed to the fact that the animals lived during the period had no hard skeletons.

Classification. The Cuddapahs are divisible into two main divisions, the Lower Cuddapah and the Upper Cuddapahs. Lower Cuddapahs are often associated with volcanic rocks.

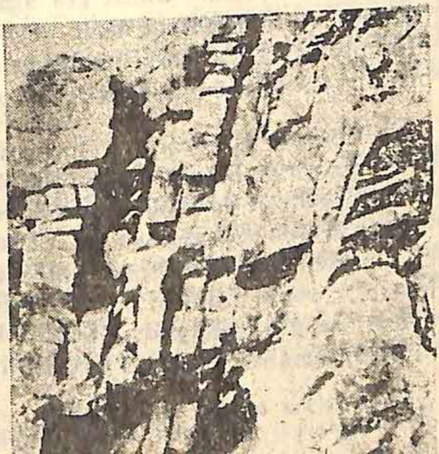
Distribution. The Cuddapah system of rocks are found in the Cuddapah and Kurnool districts in the Andhra State, Delhi, Bombay, Madhya Pradesh and Rajasthan. In the Andhra State Cuddapah formations with the overlying Kurnool system of Vindhyan rock formations form a crescent shaped outcrop whose concave border is towards

the east. The Cuddapah rocks of this area have been classified as follows :—

	Kurnool System
Upper Cuddapahs	Krishna series
	Nallamalai series
Lower Cuddapahs	Cheyair series
	Papaghani series
	Archaeans

Of these, Lower Cuddapahs are economically important because of the occurrence of large deposits of barytes and chrysotile asbestos. These deposits occur at the junction of traps with the limestones. These traps occur as intrusive sills of dolerite.

Economic Importance. The Cuddapah system is not as important as the the Dharwars in the variety and richness of the mineral wealth. Important deposits of the limestones and slates are found amongst these formations. The slates are quarried in the Kurnool district. They are used as school slates and paving slates. The banded jaspers serve as good decorative stones. Large deposits of barytes are found in the Lower Cuddapah rocks in the Cuddapah, Kurnool and Anantapur districts and Rajasthan. Chrysotile asbestos deposits of economic value occur in association with serpentine in the Lower Cuddapah formations of the Cuddapah district. Another



Delhi Quartzites of Precambrain age Showing Vertical dip—Delhi

Photo by G. Trasi.

interesting rock type from the Cuddapah rocks is the flexible sandstone of Kaliana from Rajasthan.

THE VINDHYAN SYSTEM

Introduction. The Cuddapahs were succeeded by the rocks of the Vindhyan system after a period of unconformity. This system derives its name from the Vindhya mountains which are largely made up of rocks of this formation.

Composition. The Vindhyans are, like the Cuddapahs, unfossiliferous and chiefly composed of shales, sandstones and limestones. These rocks show no evidence of serious displacements due to earth movements and are mostly found as horizontal undisturbed strata. In some places, the Vindhyan sandstones exhibit ripple marks and current bedding indicating shallow water deposition.

Classification. This system is divided into two series, Lower and Upper Vindhyans which are again subdivided because of the occurrence of intermittent beds of basal conglomerates indicating unconformity. These basal conglomerates are important as they are the chief diamond-bearing formations of the Vindhyans.

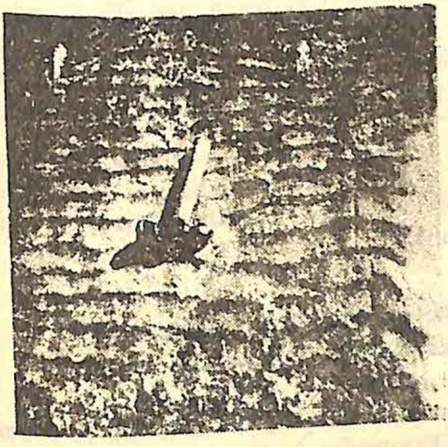
Distribution. The Vindhyan formations occupy parts of Rajasthan, Madhya Pradesh, Bihar, Cuddapah, Kurnool and Godavari valley. Vindhyan rocks of the Andhra state is of Lower Vindhyan age and is known as Kurnool system where it is well developed. The Kurnool system is interesting as it contains at the base a group of sandstones, pebbles etc., some bands of which are diamondiferous. These beds are known as Banganapalle beds. Similar formations have been found to occur in Hyderabad area and Godavari Valley.

Subdivisions of Kurnool System.

Kundair
Paniam
Jammalmadagu
Banganapalle

Economic Importance. From ancient times India has acquired a great name as the source of diamonds, all of them having been derived from the Vindhyan formations. They are obtained from

pebbles and conglomerates in the Banganapalle rocks of the Kurnool system and the Upper Vindhyan formations of Rajasthan. At the present day, however, only a few diamonds are produced annually and even those are very low in value. The important diamond-occuring localities



Ripple marks in Vindhyan Sandstones-Jaipur-Rajasthan

—Photo by M. S. Jagdeesan

are Bundelkhund which produced the famous Panna diamonds and the districts of Cuddapah, Kurnool and Bellary which produced the famous. Golconda diamonds. In addition to its ranking as the most desirable of all gems, diamond is used for many industries in cutting, grinding and boring. The world famous Kohinoor diamond which now adorns the British crown was obtained from the Golconda diamond mines.

Limestones. The limestones and shales of Vindhyan formations are the sources of raw materials for lime and cement industry, e.g., the Son valley of Bihar and the Uttar Pradesh. In the Guntur and Kurnool districts of the Andhra state limestones yield good building and ornamental stones. A particular type of rock called the flagstone is quarried in the Cuddapah and Kurnool districts. These rocks are known popularly as *Cuddapah Slabs* and have been derived from the Kurnool system.

The Vindhyan sandstones have been extensively used from ancient times for architectural purposes because of their fine and uniform grain and pleasing colour. The Buddhist stupas of Sarnath and Sanchi, the great Moghul buildings at Agra and Delhi and the modern administrative offices of the Government of India at New Delhi have all used Vindhyan sandstone in their construction.

These sandstones also serve as flagstones for flooring, roofing, pillars, fence-posts and milestones.

THE CAMBRIAN SYSTEM

Marine fossiliferous rocks of the Cambrian age are found in thick series of strata at Spiti area in the Northern Himalayas and Kashmir. These rocks contain well preserved fossils with which we are able to determine the age of this formation without much difficulty.

The lowest series of this formation which contains enormous quantities of pure comon salt is known as Saline Series. The rocks are mined at Mandi district of Himachal Pradesh. The chief rock types are shale, marl and sandstone.

THE ORDOVICIAN, SILURIAN, DEVONIAN AND CARBONIFEROUS SYSTEMS

The fossiliferous marine strata of the period Cambrian to lower carboniferous do not occur in Peninsular India, but occur in Spiti area. The chief rock types are grit, sandstone, shale, limestone and quartzite.

THE UPPER CARBONIFEROUS, PERMIAN, TRIASSIC, JURASSIC AND CRETACEOUS SYSTEMS

During this long cycle of ages different orders of geological events were in progress in the peninsular and extra peninsular regions of India. The Upper Carboniferous period was a period of stupendous changes on the surface of the globe. It brought into existence a great central ocean called Tethys Ocean, separating Laurasia and Gondwana land, the two huge land masses in the northern and southern hemispheres respectively Tethys Ocean extended, so far as we know, from China to Spain, in which sediments were deposited continuosly from the Upper Carboniferous to Eocens. These constitute the marine geosynclinal deposits of these periods in the extra peninsular region. In contrast to this are found in peninsular region fresh water formations with rich deposits of coal indicating luxuriant vegetation during that period These rocks constitute the Gondwana system.

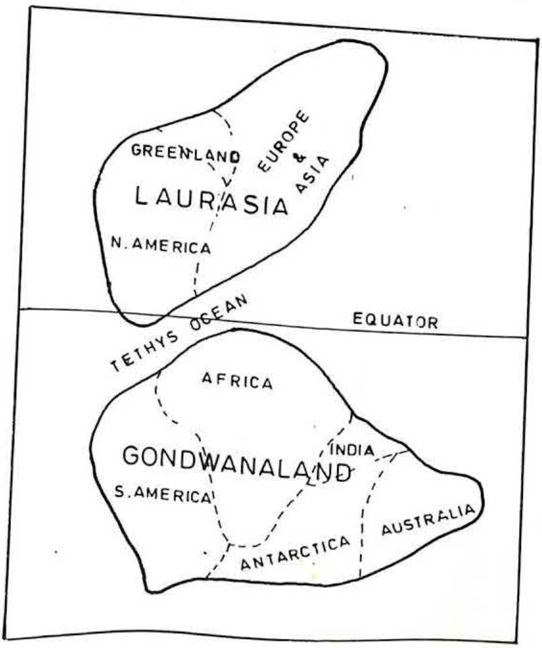
Introduction. After the deposition of the Vindhyan rocks and their uplift into land, there was a great hiatus in the stratigraphical history of the peninsula. At the end of the palaeozoic era towards

There rolls the deep where grew the tree.
O earth, what changes hast thou seen!
There where the long street roars, hath been
The stillness of the central sea.

Lord Tennyson.



The break-up of Gondwanaland and the consequent drift of the constituent continents.



The two huge land masses, the one in the northern hemisphere designated Laurasia and the other in the southern hemisphere called Gondwanaland, with the Tethys Ocean separating them.

upper carboniferous period, a new series of changes took place over the surface of the globe which brought about a redistribution of the land and sea. At this time there existed a great southern continent or a series of land masses which were connected closely enough to permit the free distribution of terrestrial fauna and flora. The fossils of plants and animals found in these regions show close affinities to prove that these land areas were once together. This southern continent included India, parts of the Malay Archipelago, Australia, South America, South Africa and Madagascar which were probably at that time very close together. This southern continent is known as the Gondwana Land. This is named so after the Gondwana formations which derived its name from the Gond kingdom of Madhya Pradesh where these formations were studied first. This Gondwana continent existed upto the end of the Mesozoic era when it was broken up by sinking of certain connecting areas or by the drifting away of the component parts.

Composition. The rocks forming this system are of *fluviatile* or *lacustrine* (fresh water) nature and were deposited in a series of large river or lake basins which gradually sank along trough faults, amidst ancient rocks. It is to this faulting that we owe the preservation of the Gondwana strata with their coal seams. These formations are chiefly composed of shales, clays and sandstones with intercalated plant remains which now occur as coal seams.

Distribution. The three large prominent Gondwana areas are as follows :—

1. The large linear tract in Bengal and Bihar along the valley of Damodar river and Son valley.

2. An expansive outcrop in the Madhya Pradesh in the south-east direction in a belt approximately following the Mahanadi valley.

3. A series of more or less connected troughs along the Godavari valley.

Besides these main areas upper Gondwana rocks occur in Kathiawar, Kutch, Rajasthan and along East coast of India. These rocks are also met with in the extra-peninsular regions of Kashmir.

Classification. The Gondwana system is divided into two major divisions based mainly on palaeontological evidence as lower and upper divisions, each characterised by distinct flora.

Upper Gondwanas—Rajmahal flora

Lower Gondwanas—Glossopteris flora

Subdivision. The lower as well as the upper Gondwanas consist of three series each. In ascending order they are the Talchir, Damodar and Panchet series in the lower division and the Mahadeva, Rajmahal and Jubbalpur series in the upper division. Each series consists of different stages.

Talchir Series. The lowest series of this system is named after the coal field in the state of Talchir in Orissa. This consists of smooth striated boulders, sandstones containing undecomposed felspars and shales, indicating glacial period.

Damodar series is divided into four stages namely Karaharbari, Barakar, Barren Measures and Raniganj. This series takes its name from the Damodar river, a tributary to the Hoogly river which flows through the Raniganj, Jharia and Bokaro fields and is the most extensive and best developed subdivision of the Gondwana system. Of the four sub-divisions, coal seam is completely absent in the third division; hence it is known as Barren Measures. But it contains ironstone shales in which are found lodes of workable iron ore. Of the other three divisions Barakar and Raniganj stages contain important coal seams.

Panchet series, named after the Panchet hill, overlies the Raniganj stage and is of interest only because of its fossil content.

The Upper Gondwana rocks are of great interest for their fossil content of plants and huge reptilian bones (Dinosaurs). Economically they are not so important as the lower division as they do not contain workable coal seams. But sandstones of this formation serve as good and durable building stones.

The Gondwana formations found along the East coast of India are of Upper Gondwana age and they occur in Cuttack in Orissa, Rajmundry and Vijayawada in the Andhra state, Sriperambadur in Chingelpet district and near Uttatur in the Tiruchirapalli district of Tamil Nadu.

Economic Importance. The main importance of the Gondwana system centres around coal; but there are deposits of various types

of clay, sandstones and ironstone shales, which are of some importance.

Clays. Fire-clay deposits are found in association with the coal seams of the Barakar stage. They are used for the manufacture of refractory bricks. Other types of clay available from this strata are useful for making bricks, pottery, terra-cotta and Chinaware. Factories utilising clays of various description are situated in the Raniganj, Jharia and Jabalpur areas.

Sandstones serve as good building stones. Ahmednagar sandstone of Idar State has been used in the delicate tracery that adorns the mosques of Ahmedabad. Athgarh sandstone of Orissa has been employed in the magnificent temples of Puri Jagannath, Bhuvaneshwar and Konarak. It is fine grained and has retained the sharpness and delicacy of carved work very well through more than ten centuries.

Iron Ore. Pockets of limonitic iron ores and ochres are found in the lower Gondwana rocks.

Coal. Of the total coal production in India, 98% of coal is supplied by the Gondwana fields and 2% by the tertiary fields.

Important Gondwana Coalfields in India. Raniganj, Jharia, Giridih and Bokaro in Bihar; Talchir in Orissa; Hura and Brahmani in Bengal; Umaria and Sohagpur in Rajasthan; Bellarpur and Pench valley in Madhya Pradesh; Singareni and Kothagudam in Hyderabad.

Gondwana coals are good steam and gas coals. The best coking coals are chiefly confined to Jharia, Giridih and Bokaro fields. A part of the coal in Giridih is exceptionally good being very low in phosphorous and useful for the manufacture of ferro-alloys like ferro-manganese.

THE TRIASSIC SYSTEM

Marine Triassic formations occur in Northern Himalayas. During this period all major group of animals existed except birds and mammals.

THE JURASSIC SYSTEM

Occurs in Kutch, Rajasthan and parts of East Coast. They are important in the Kutch area as they contain thick fossiliferous strata.

THE CRETACEOUS SYSTEM

Introduction. The Cretaceous system is one of the most widely distributed sedimentary systems in India and represents a variety of facies. The Himalayan area as in the earlier systems, shows geosynclinal facies. The peninsular area shows coastal facies. They occur in Narbada valley, Tiruchirapalli and Assam. Coastal formations are formed due to marine transgressions. Esturine or Lacustrine deposits are developed in various parts of the central peninsula which now underlies the great group of lava flows known as the Deccan Traps. These formations are called *infra-trappean rocks.*

An igneous facies is represented in its intrusive and extrusive phases by the records of the gigantic volcanic out-bursts in the peninsular India and by numerous intrusions of granite and other plutonic rocks in many parts of the Himalayas. This heterogeneous constitution of the Cretaceous is a proof of diversified physical conditions that existed in India at the time of this formation.

Composition. Chiefly composed of shales, limestones, sands and clays with fossils.

Distribution. These Rocks occur in Narbada valley, Southern Tamil Nadu and Assam.

Cretaceous rocks are found in Tamil Nadu at Pondicherry, Vridhachalam and Tiruchirapalli. The largest of these occurs in north east of Tiruchirapalli district. Cretaceous beds of this area are divided into four stages. They are in the ascending order Uttattur, Tiruchirapalli, Ariyalur, and Niniyur.

Uttattur Stage. This had been named after the village Uttattur and consists chiefly of fine silts and sandy clay, phosphatic and calcareous nodules, gypsum and celestite salts. This stage contains at its base a dark grey weathered limestone consisting of corals. It is locally used as a building stone. Thick extensive beds of gypsum and celestite salts suggest that before deposition of next stage over Uttattur beds there must have been a period of interval when the sea became desiccated impregnating the sediments with salts.

Tiruchirapalli Stage which overlies the Uttattur stage with a slight unconformity consists of sandstones, shales and shell limestones. This shell limestone takes good polish and is used as an ornamental stone. Silicified large trunks of trees and broken pieces of fossil wood occur in this stage. Overlying these beds occur *Ariyalur* and

Niniyur stages which are of great palaeontological interest.

Economic Importance. The minerals, gypsum and celestite and the rock deposits, phosphatic nodules, coral limestone and shell limestone are of importance.

THE DECCAN TRAPS

Introduction. The close of the mesozoic era was marked by the outpouring of enormous lava flows which spread over vast areas of Western and Central India. They were issued from long narrow fissures in the earth's crust. They occur as horizontal bedded sheets of basalt. This great volcanic formation is known in Indian Geology as the Deccan Traps because of their steplike or terraced appearance.

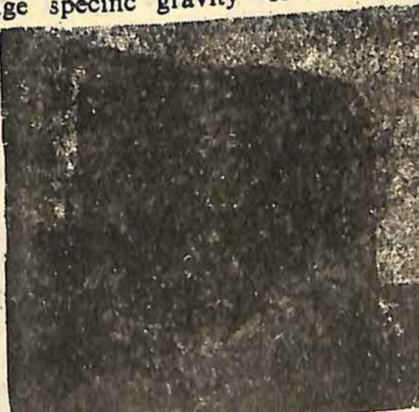
Distribution and Extent. The area now occupied is about 200,000 sq. miles including Bombay, Kutch, Kathiawar, Madhya Pradesh, Maharashtra, Rajasthan and parts of the Deccan.



Fig. 89. Trap country.

Structural Features. The trap country is characterised by flat topped hills and step-like terraces (trap means steps or stairs in the Swedish language).

Petrology. The Deccan Trap rocks are dark coloured and basaltic in composition with an average specific gravity of 2.9. They are mainly of two types, vesicular and non-vesicular. Zeolites, calcites, amethyst and chalcedony occur as fillings in the vesicular basalts.



Columnar Jointing in basalts-Deccan Traps. Andheri-Bombay

—Photo by M. S. Jagadeesan

Alteration and Weathering of the Traps. The Traps weather with characteristic spheroidal exfoliation which

give rise to large boulders. Traps give rise to deep red soil or black cotton soil known as regur which can be seen in many parts of Deccan. Another product of weathering is laterite.

Fluviatile or lacustrine deposits formed during the interval between successive eruptions occur with the lava flows. The fossils of plants and animals found in these intervening beds indicate the age of beds and of the associated Traps. These beds are known as *inter-trappean beds.*

Economic Importance. Deccan traps serve as good building stones, but they are not usually preferred because of the dark colour. These rocks are excellent for macadam and tarred roads. They are hard, tough, wear resisting and have good binding properties. They are also excellent for use as aggregates in cement concrete. The Deccan Traps of Western India are a great storehouse of quartz, amethyst, agate, chalcedony and its other varieties which are used as semi-precious stones. There are small agate cutting industries at Ratnagiri, Rajpipla and Cambay. The traps are often capped by ferruginous and aluminous laterite, the latter being found in several places, e.g., Kolhapur, Belgaum, Katni and Jabalpur. It is rich enough in alumina to be high grade bauxite. Bauxite is useful in petroleum filtration and in the manufacture of aluminium and alumina cements. The black cotton soil is rich in plant nutrients on which cotton and certain other dry crops flourish. Conditions of underground water storage and supply in the Deccan Trap areas are of interest. The vesicular parts of bedded lavas make good aquifers and yield fair supplies of underground water.

THE TERTIARY SYSTEM

Introduction. This era is the most important in the physical history of the Indian region, as it was in this period the present configuration of the country was obtained. The two great earth movements which were chiefly responsible are (1) breaking of the old Gondwana continent by submergence of large segments underneath the sea and by drifting away of some of the component parts and (2) uplift of the tethyan geosynclinal tract of sea deposits to the North into the lofty chain of Himalayas. These great changes which took place at the end of mesazoic era affected animal and vegetable life profoundly. During this period the mammals among the animals began to gain

importance and plants of earlier eras were replaced by the flowering plants.

Composition. Composed chiefly of shales, sandstones, limestones, gravel and marl.

Distribution. Extra-peninsular region shows a great development of the Tertiary rocks continuously along the mountainous tracts of Sind, Kashmir and runs along the Himalayan foot hills. In peninsular India the Tertiary rocks are found in parts of Gujarat, Kutch, Orissa, Kerala and Tamil Nadu.

Rise of Himalayas took place in four great movements. The Upper Tertiary rocks of Himalayas are called the Siwalik system after the Siwalik hills near Hardwar. These deposits are important for the rich collection of mammalian fauna which suffered exitinction during the third upheaval of Himalayas and with the incoming of Pleistocene Glacial conditions.

Economic Importance. Tertiary rocks in extra-peninsular regions of Assam are chief sources of petroleum. Chief oil-fields are Digboi in Assam and Ankleshwar in Gujarat.

Laterite a variety of rock found along the West Coast of Malabar and other places in India, serves as a fairly good building stone.

Coal. Lignite variety occurs at Punjab, Rajasthan, Assam and Neyveli near Cuddalore in South Arcot District of Tamil Nadu

LIGNITE DEPOSITS OF TAMIL NADU

The discovery of large deposits of lignite, a member of the coal family, in South Arcot district in Tamil Nadu brings a new factor into the economy of South India. The deposits extending over a 100 square mile area are estimated to be around 2,000 million tons. If successfully developed and exploited these lignite deposits will not only cater to fuel needs present and future, but also pave the way for the establishment of an Iron and Steel Industry in Tamil Nadu utilising the Salem iron ore deposits.

Lignite is used as fuel in electrical power industry, in the manufacture of synthetic petroleum, for extraction of montane wax which is used in making gramophone records, shoe polish, candles and rubber boots. Also used in the manufacture of fertilisers and drugs.

THE PLEISTOCENE SYSTEM

Introduction. The Pleistocene system includes alluvial formations of Sutlej, Narbada, Tapti, Krishna, Godavari and Indo Gangetic plains. As in other parts of the world Pleistocene deposits in India contain relics and bones of pre-historic men indicating origin of Man.

Economic Importance. Alluvial plains constitute the wealth of India. Clays are used for rude earthenware and brick making and Kankar for lime, cement and road construction. These plains are an immense reservoir of fresh sweet water available by ordinary wells.

QUESTIONS

GROUP A

I. Match the following :

1. Gondites	(a) Tajmahal
2. Charnockites	(b) Purijagannath Temple
3. Makrana Marble	(c) Coal field
4. Athgarh sandstone	(d) Seven pagodas of Mahabalipuram
5. Jharia	(e) Manganese ores
6. Gypsum beds	(f) Oil field
7. Deccan Traps	(g) Cretaceous rocks of Trichirapalli
8. Magnesite	(h) Salem Chalk hills
9. Vindhyan sandstone	(i) Red fort, Delhi
10. Ankleshwar	(j) Zeolites

II. Decide whether these statements are true or false. Reword the false statements to make them true.

(a) Diamondiferous beds occur in the Vindhyan system of rocks in India.

(b) Petroleum occurs as oil pools in the rocks of the precambrian era known as purana group of rocks in India.

(c) Lignite beds occur in Tertiary rocks of South Arcot district in Madras State.

(d) Tethys is the name of a great mountain chain that existed in the geologic past.

(e) Important coal fields of India occur in the Gondwana formations of India.

III. Fill up the blanks with the appropriate terms or words :

1. Gold occurs in Quartz veins of the..........................rocks of Mysore in Kolar Gold fields.
2. Copper ores are found in..............................district of Bihar and the chief ores are..
3. Mica occurs in the Pegmatite dikes in.......................... district of Bihar and...............................district of Andhra Pradesh.
4. The great volcanic formations found in the vast areas of western and central India is known as..........................
5. In early periods, the Cuddapah and Vindhyan rocks were referred to as........................formation because of their association with diamonds.............

Group B

I. The Dharwarian rocks and the associated gneisses constitute the most important mineral bearing formation of India—comment.

II. Describe the stratigraphy and economic importance of any one of the following

(a) Cuddapah System (b) Vindhyan System (c) Gondwana System

III. Write short notes on :

(i) Deccan Traps (ii) Uttattur beds (iii) Charnockites (iv) Salt range.

IV. Name the localities and geological formations in which the following minerals are found in India

1. Gold 2. Lignite 3. Gypsum 4. Mica 5. Pyrolusite 6. Barite 7. Petroleum 8. Magnetite 9. Beryl 10. Bauxite.

V. Write an essay on the mineral wealth of India.

(Also see Appendix)

ENGINEERING GEOLOGY

In recent years the use of geological knowledge has greatly increased in many phases of engineering construction, viz., the building of dams, tunnels, laying of mountain roads and tapping of underground water resources. Geological knowledge is also useful in the selection of stones suitable for various purposes such as the construction of dams, bridges, roads and buildings. It also helps a great deal for easy procurement of building stones from the very locality or nearby area, where the constructions have to be carried out by knowing the geological formations of that place and thereby avoiding unnecessary cost of transport of building stones from a far off place.

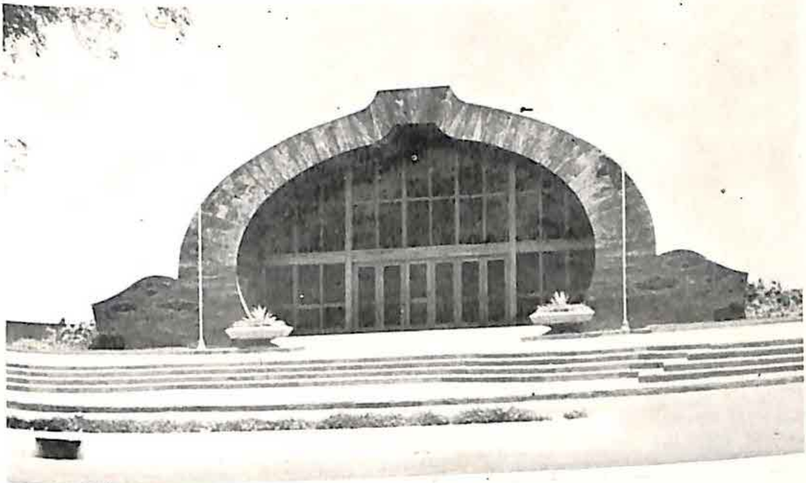
BUILDING STONES

These include the various kinds of rocks which are dressed and trimmed to shape and utilised for construction and ornamentation purposes. For a good building stone certain geological and physical properties are necessary, such as pleasing appearance, durability and ease of processing in quarrying.

For determining the suitability and durability of building stones their mineralogical composition should be known. The minerals like chert, pyrite and large quantities of mica are injurious and harmful and their presence should be avoided. The stones containing minerals like pyrite that oxidise and produce unsightly stains are undesirable. The fine grained rocks will be stronger than those which are coarse grained. The durability of a stone is its capacity for retaining its original size, strength and appearance for a long period and this depends upon its capacity to withstand the weathering conditions, viz., the action of atmosphere and rains.

For selection of good building stones, the other properties like absorption, crushing strength, fire resistance and resistance to weathering should also be ascertained in the laboratory.

The common rock types which are used in buildings and other constructions are granites and related igneous rocks, limestone, marble, slate, sandstone and soapstone.



(Photo by Rajbir Singh)
Front view of the celebrated 'Vigyan Bhavan'
One of the landmarks in India's capital, New Delhi.

The Vigyan Bhavan is the venue for important seminars and conferences. The twenty-second International Geological Conference 1964, was held here. This front view illustrates the typical use of a variety of marble popularly termed 'Baroda Green' enhancing the beauty of the structure. This arch is a replica of the arch entrance to the famous Ajanta caves in Maharashtra. Such marbles present in the Dharwarian rocks in Rajasthan are of high decorative value being available in fifteen different colours. They are highly prized for foundation tablets. The statues of Tamil saints and poets installed along the marina beach in Madras, have their pedestals embedded with this quality of marble.

Among the igneous and igneous metamorphosed rocks, mostly granites and gneisses are used. Granites are used on account of their even granular texture, pleasing colour and favourable physical properties like high crushing strength and low absorption. They can be easily quarried on account of certain well developed joints and divisional planes.

Basalts and dolerites serve as excellent road-metal but they are not usually preferred for building purposes because of their dark and dull colours.

Sandstone and quartzites which are of abundant occurrence are also used for building purposes. Quar' 'te is not usually used in masonry because of its extreme hardness which renders working difficult.

Limestones can be quarried easily and they are chiefly used for buildings because of their light and pleasing colours. Marbles and ophicalcites are used for decorative work in buildings.

Slate, a kind of metamorphic rock which can be split evenly into thin layers is used chiefly for roofing and paving in buildings.

Laterite is a good and durable building stone. It is used as a road metal when available in large quantities especially in tropical countries like India.

With the introduction of the use of cement concrete in buildings and other constructions, rocks are broken into aggregates and used largely for cement concrete.

Granites, quartzites and Basalts serve as excellent aggregates for cement concrete.

Presence of the following silicate and silica minerals are not desirable in aggregates of cement concrete as they are reactive with high alkali cements—opal, chalcedony, chert, volcanic glassy rocks like rhyolite and rhyolite tuffs. During the mixing of aggregates with cement and water, the alkalies in cement get dissolved in water and increases in concentration slowly. This caustic liquid begins to react with the reactive aggregate particles resulting in the formation of alkali silica gels. This results in cracking near the reactive particles. This

gradually extends to the surface of the concrete with the exudation of gel along the cracks. This reaction may be controlled by using low alkali cements containing less than 0.6 percent of sodium and potassium oxides.

In modern buildings concrete and reinforced concrete walls are faced with stones to give them attractive appearance and protection from rain water and atmospheric gas action. Natural stones add beauty and grandeur to buildings. Moreover the upkeep and maintenance of the structures in stone are not difficult. The granites and limestones are used widely as facing stones.

BUILDING STONES OF INDIA

Granites and granitic gneisses available in plenty in the oldest crystalline Archaean rocks of India have been used in the construction of most of the temples and public edifices in Southern India. Charnockite a variety of granite serves as an excellent building stone and out of this rock are hewn out the seven pagodas at Mahabalipuram near Madras. The Vindhyan sandstone and sandstones of other older formations are used extensively as building stone in India. The Buddhist Stupas of Sarnath, Barhut, Sanchi, Emperor Akbar's city of Fateh-pur Sikri near Agra and the famous Moghul buildings at Agra, Delhi and Lahore, and the Rashtrapati Bhavan, Lok Sabha buildings and the modern administraive offices of the Government of India at New Delhi have been built of in Vindhyan Sandstones. Vindhyan sandstones are also used as flagstones for flooring and roofing, window sills, telegraph poles, milestones etc.

Another variety of sandstone of great beauty and durability is the Athgarh sandstone obtained from the upper Gondwana rocks in Orissa. The celebrated temples of Puri-Jagannath, Bhuvaneshwar, Konarak and the Buddhist caves at Kandagiri and Udayagiri have been hewn out of these sandstones. The Tirupathi sandstones of Andhra Pradesh and the Sathyavedu Sand stones of Tamil Nadu, used in buildings are also obtained from the Gondwana formations.

Limestones which serve as excellent building and ornamental stone are found in many places in India and in most of the geological formations in India. The world famous Taj-Mahal has been built of the Makrana marble of Archaen Dharwars.

The limestones from Guntur and Kurnool districts are capable of yielding excellent building stones. The limestones quarried in Andhra Pradesh near Yerragunta (Cuddapah Dt.) Betamcherla (Kurnool Dt.) are popularly known as Cuddapah slabs and are widely used as paving stones, fence stones, steps and table tops. They are capable of taking a fairly good polish and can be split into slabs. half an inch or more in thickness and up to 6 ft. by 4 ft. in size.

Laterite which occurs extensively along the West Coast of Malabar, Maharashtra, Madhya Pradesh and other places in India serves as a fairly good and durable building stone from the facility with which they are cut into bricks or blocks when freshly quarried and their property of hardening with exposure to air. It is used also as a road metal because of its abundant occurrence.

Slates are quarried in India near Dharmasala in Kangra district, Kund in Gurgaon district, Monghyr in Bihar and Markapur on the Nellore-Kurnool border.

QUARRYING

There are two distinct types : one employed in the quarrying of building stones for which purpose the stone must be obtained in large and unshattered blocks or masses; the other in quarrying of stone in rough irregular shapes for road metal, concrete aggregate, fluxing and various other manufacturing processes.

Methods of quarrying vary with the composition and hardness of the rocks, their structure, cleavage and other physical properties and also the position and character of the deposits. The fundamental principle of quarrying is to arrange the working face of a quarry in such a way that the rock will slip free and slide forward chiefly by its own weight. In other words, it is to reproduce land slips of an economic value.

Prospecting and Development. Development work should not be started of a deposit without reasonable assurance of an available mass of rock, sufficiently high in quality and abundant in supply for profitable exploitation.

A cliff or escarpment along a stream or gulley is especially valuable because it provides a cross section which permits tests for quality at

various levels. If such a cross section is not available in nature, test holes are drilled at such intervals as will supply adequate data on the whole area under consideration.

The prospecting method is governed to some extent by the type of operation. If the chemical composition of rock is of primary importance as in furnace flux, lime or cement material, churn drill cuttings will supply materials for chemical analysis.

For building stones or dimension stones and most crushed stone uses the physical properties are more important than the chemical

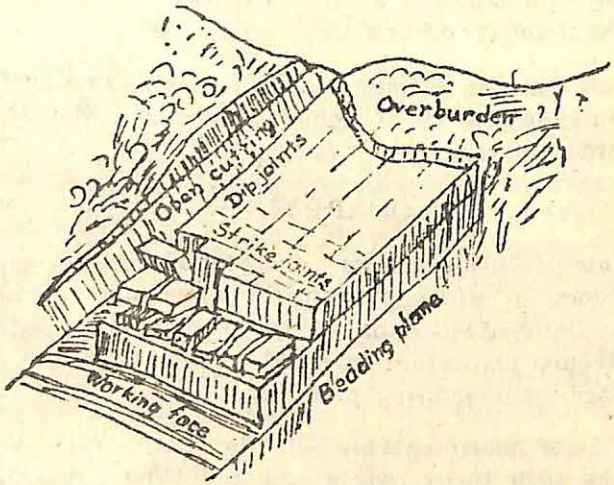


Fig. 90. Sandstone quarry.

properties. Building stones must be free from cracks, of uniform texture; attractive colour and for some uses capable of taking a polish. For crushed stone use rocks must have satisfactory strength, soundness and low absorption. The term *dimension stone* is generally applied to masses of stones required for use in the form of blocks of specified shapes and usually of specified sizes. Other forms that find commercial use are designated broken, crushed or pulverised stones. Stone fragments that are classed in the second group may be of specified sizes and sizing is usually accomplished by screening.

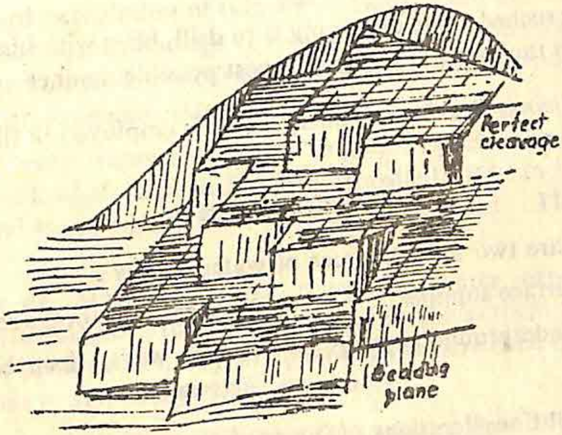


Fig. 91. Slate quarry.

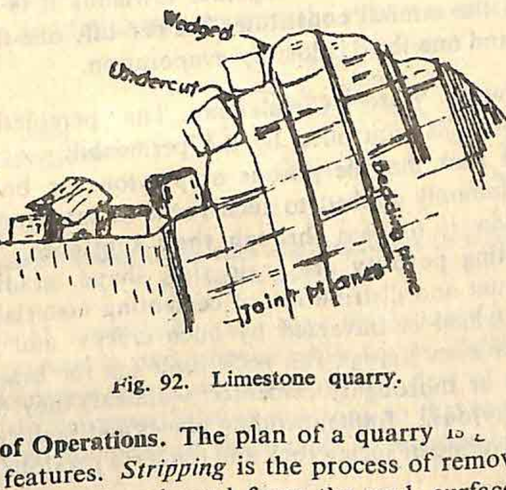


Fig. 92. Limestone quarry.

Methods of Operations. The plan of a quarry is [illegible]erned chiefly by geological features. *Stripping* is the process of removing the overburden of clay, gravel and sand from the rock surface. The three important methods of quarrying are—

(i) The *plug and feather method* or wedging and cutting method as in sandstone quarry.

(ii) *Explosive or blasting method.* This is used in crushed stone quarrying and has become important since the commencement of improved [illegible]ays and the extensive use of cement concrete. The

object of crushed stone quarrying is to drill, blast with high explosives and quarry the material in the cheapest possible manner.

(iii) *Channelling by machinery*. This is employed in the quarrying of limestones.

WATER SUPPLY

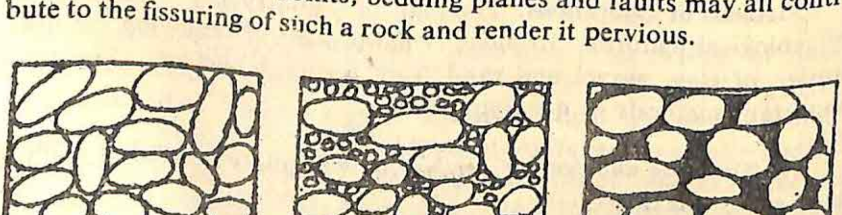
There are two main sources of water supply .

(1) Surface supplies —Rivers and storage reservoirs

(2) Underground supplies —From wells, deep borings and artesian water.

Rainfall Considerations. The rainfall on any land area is dispersed partly by the run-off from the surface and partly by percolation into the ground. In moist temperate lowlands it is estimated that one-third of the rainfall constitutes the run-off, one-third sinks into the ground and one-third is lost by evaporation.

Underground Water Circulation. The percolation of water into the ground is controlled by the permeability of certain rocks. A permeable rock may be porous or pervious or both. The term porous is commonly applied to such rocks as sandstones which hold water or allow it to pass through their substance. The principal factors affecting porosity are grain size, shape, grading or sorting and the amount and distribution of cementing material. A pervious rock is one which is traversed by open cracks and fissures which contain water even though the rock itself (as for example a typical igneous rock or thoroughly cemented sediment) may be so compact as to be impervious. Joints, bedding planes and faults may all contribute to the fissuring of such a rock and render it pervious.



(a) (b) (c)

Fig. 93. (a) Uniform grain deposit having much more spa... (b) Poorly assorted deposit having little pore space. (c) Grains cemented with mineral matter having little pore space.

Downward percolation of rain water alone is not the only source of underground water, though it is the principal one. In addition to such water known as meteoric, there are two other kinds, *connate and juvenile* or *magmatic water*.

Connate water represents water originally present in the pore-spaces of a rock when its particles were deposited. It is, in fact, water of the original sea in which the sediments accumulated. This is saline in character.

Juvenile or *Magmatic water* represents water expelled from cooling igneous magmas that were brought to the surface from great depths of the earth's crust. Most mineral veins have been precipitated from solutions in ascending magmatic waters.

Water–Table. A large amount of rain water sinks into the ground, and below a certain depth of the soil the rocks are saturated. The top of the saturated zone is known as water-table. This surface rises under hills and falls away towards the stream courses.

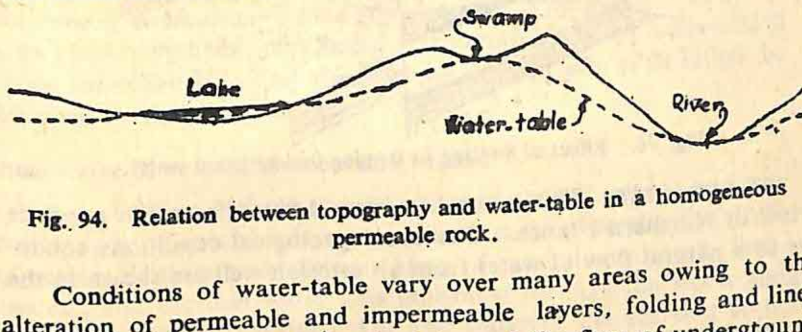


Fig. 94. Relation between topography and water-table in a homogeneous permeable rock.

Conditions of water-table vary over many areas owing to the alteration of permeable and impermeable layers, folding and lines of faulting. Impermeable layers interrupt the flow of underground water and isolate the water bearing horizons so that each permeable group has its own independent water-table. Outcrops of such layers

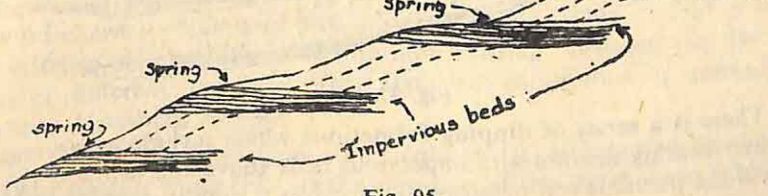


Fig. 95.

are commonly responsible for lines of intermittent springs along a hill side as in Fig. 95. Faults generally affect the water-table by blocking or diverting the flow, sometimes providing an outlet to underground water that would not otherwise be available as in fig. 96.

Wells. Wells are controlled outlets where underground water has been made available for human needs. Wells should be sunk deeper to the lowest level of the water-table. In the case of shallow wells sunk into water bearing strata at or near the surface especially in populous districts, the water is apt to be contaminated by sewage or other surface sources of pollution. Deep wells, if lined to some depth from the surface usually afford larger and purer supplies.

The most favourable of all sites for well is provided by a synclinal trough of alternating layers of permeable and impermeable beds of rocks providing artesian conditions.

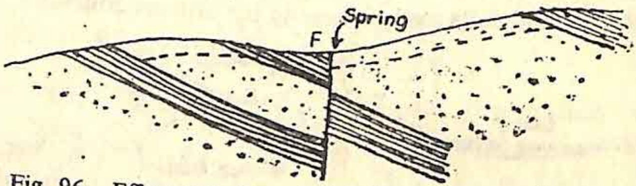


Fig. 96. Effect of faulting in tapping underground water.

Artesian wells. This name has been derived from the province Artois in Northern France. The usual geological conditions conducive to a natural flow of water from an artesian well are shown in the figure.

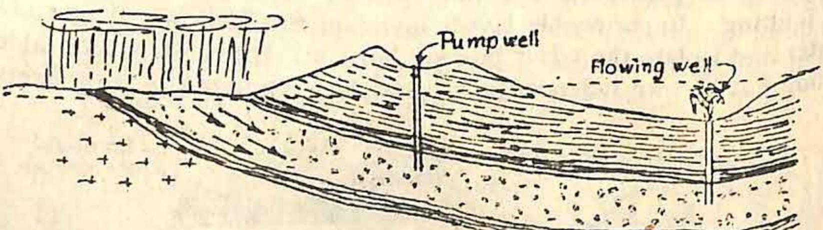


Fig. 97.

There is a series of dipping formations which include a pervious or water-bearing stratum with impervious beds above and below. The edge of the pervious bed outcrops and receives a supply of water from

the surface. The water filling pores of the pervious bed, is therefore under pressure and when this pressure is released by a well, the water seeking its own level rises to a height which may be almost equal to that of the outcrop of the pervious layer.

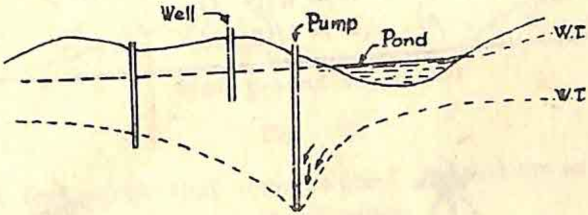


Fig. 98.

When water is pumped continuously from a well the rate of flow through the rocks is usually insufficient to maintain the original head and the water-table is lowered around it. Thus there is produced a more or less conical depression of the water table around the well, known as the *cone of exhaustion* or *cone of depression.* A deep well from which a large yield is pumped, may bring neighbouring smaller wells within its cone of exhaustion, and these being drained dry must either be abandoned or sunk deeper.

Ground water in coastal districts and islands

The occurrence of fresh ground water in coastal regions and certain islands is of special interest. In these areas generally the strata is of permeable nature chiefly consisting of sand, loam, corals, limestones etc. and the rain water gets infiltrated through the strata and occurs as fresh ground water. The salt water of the sea that seeps into the substratum makes the fresh water float over it because of the difference in densities. The level of fresh water occurs usually at an altitude slightly above the sea level. It is found that for every foot of fresh water that extends above the sea level, it continues downward 40' below sea level. It is due to the fact that a column of fresh water 41' will balance a column of salt water 40' high. This condition is attributed to a hydrostatic equilibrium existing between the two fluids of different densities. This state of equilibrium is termed Ghyben—Hertsberg balance.

In Fig. 99 the fresh water column (H) is balanced by the height of the salt water (h). If the elevation of the fresh water table

above the sea level be (t) then (H) is equal to h+t. The whole relationship may be derived thus :

$$(h + t) = hg$$
$$t = hg - h$$
$$\text{or} \quad t = h(g-1)$$
$$\text{or} \quad h = t/(g-1)$$

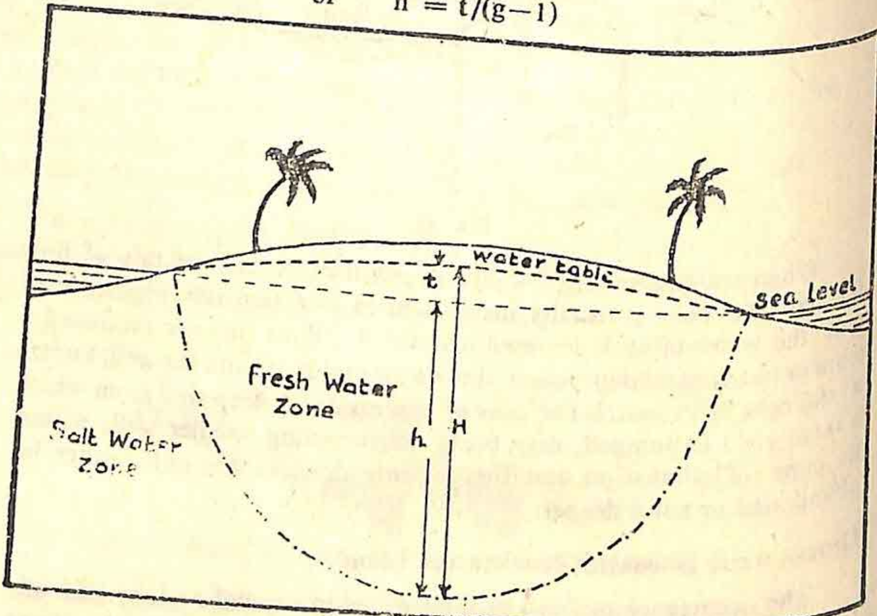


Fig. 99.

(where g is the sp. gr. of the salt water). As there is a definite relationship between occurrence of the salt water and fresh ground water, sea water intrusion or salt water contamination may be checked in the coastal regions and islands by proper methods of control.

Ground Water Survey. A knowledge of the geology of the district, its topography and surface indications, affords valuable help in the location of ground water. Swarming of insects in the evenings at certain points on the surface during the dry season and existence of green grass vegetation are indications of *perched* or *suspended* water-table.

For the detection of deep-seated springs a knowledge of the structure of the rock and its outcrop is an important factor.

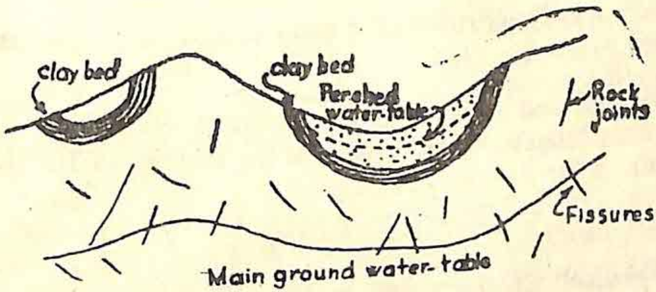


Fig. 100.

Rock formations that serve as good aquifers are as follows :—

Gravel, sand and sandstone, alluvium.
Limestone with cavities formed due to the action of acid waters.
Marble with fissures and cracks.
Granite rocks with fissures and joints.
Weathered gneisses and schists.
Heavily shattered quartzites.
Slate (better than shale owing to its jointed condition).

Ground water occurrences in India

The river plains of Indus and Ganges are a great reservoir of fresh sweet water available by wells. In hilly tracts of the country, springs are common where pervious and impervious strata are interbedded and inclined or folded or when rocks are traversed by joints, fissures, and faults. In Deccan trap formations of Maharashtra and Madhya Pradesh the vesicular basalts form good aquifers and yield ground water.

Artesian springs are met with in Gujarat, South Arcot in Tamil Nadu, Pondicherry, and East and West Godavari districts in the Andhra Pradesh.

In deltaic region of the Tanjore, Tiruchirapalli, Madurai and Tinnevelly districts of Tamil Nadu the subsoil is clay or soft rock and it yields a fair quantity of good water. In Coimbatore and the central districts of Tamil Nadu, the substratum consists of rock at a moderate depth and the chances of striking artesian springs are not so great as in the coastal areas.

In the West Coast regions like Kerala and Karnataka the subs-

tratum is mostly lateritic and a good yield of ground water may be expected.

Thermal and Mineral springs occur in many parts of India —Bombay, Punjab, Bihar, Assam, in the foothills of Himalayas and Kashmir.

DAMS

Geological Considerations in the Construction of Dams. The first consideration in *all dam sites*, is the suitability of the rock in foundations. The chief geological considerations in the selection of sites for dams are :—

1. The underlying rocks must be strong enough to withstand the weight of the dam and the resultant thrust (due to push of water).

2. The rocks should be sufficiently impervious to prevent serious passage of water beneath the sole of the dam.

3. The rocks should be free from fissures, joints and faults so that there is no serious leakage of water.

The best site for a dam is therefore an impervious band of strong massive rocks which are free from joints throughout the length of the dam. Granite free from joints and fissures would make an excellent foundation for any dam.

When a river breaks across a ridge by cutting a deep gorge at right angles to the strike of bedded or foliated rocks, an ideal dam site may be found in the gorge.

High dam cannot be efficiently founded on loose, unconsolidated strata like sand and loam because the loss by percolation or leakage would be considerable. It is possible to construct low pressure dams in such areas if they have sufficiently wide foundations without openings or crevices.

No dam is to be constructed across a fault plane. Small fissures and joints can be sealed with concreting material. But in the case of a fault even after sealing it may give way or widen at the time of earthquakes. Hence it is not reliable.

Massive solid rocks such as granite, trap, quartzite limestone

and sandstone (fine textured), if free from open joints and fissures make excellent sites for the foundation of dams. Percolation of water is possible through decomposed rocks (dolerite and laterite) and hence they should be avoided.

Considerations in the construction of dams on bedded or foliated rocks. An erosion valley in an anticlinal flexture (fig. 101). A dam founded in this valley will be efficient upto the height of marl as it will be water-tight. Above this, leakage will take place through the sandstones on each side. But a dam upto this marl can be constructed safely.

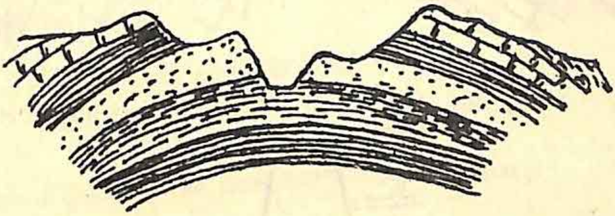


Fig. 101.

A typical erosion valley in mountainous country showing anticlinal flexure in valley, floor as shown in figure 102 renders such a site unsuitable for a dam as the sandstone is exposed in the stream bed.



Fig. 102.

Among stratified rocks consisting of impervious beds interbanded with porous strata the dam should be built with its length parallel to the strike of beds and foundations should be so laid out as to have an apron of impervious strata under the upstream side of the dam.

In tilted strata it is preferable to locate the foundation of the dam on beds having upstream dips (fig. 103) rather than steeply inclined rocks dipping downstream (fig. 104). The latter are preferred to rocks

gently dipping downstream (fig. 105). In folded rocks dams are with advanta founded exactly or very slightly on the upstream side of the

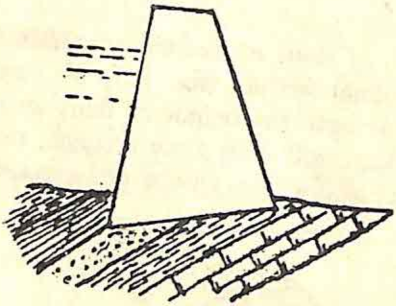


Fig. 103.

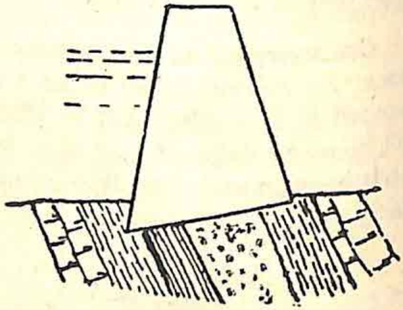


Fig. 104.

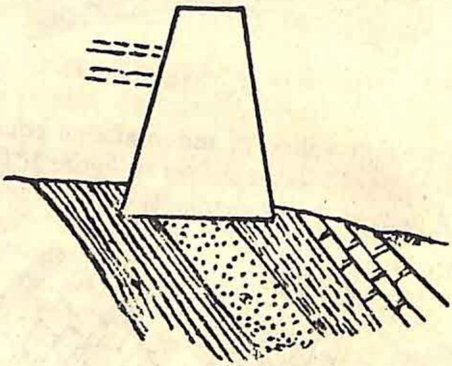


Fig. 105.

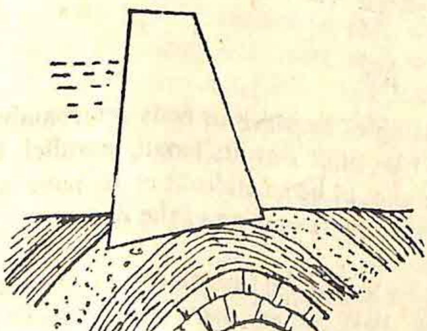


Fig. 106.

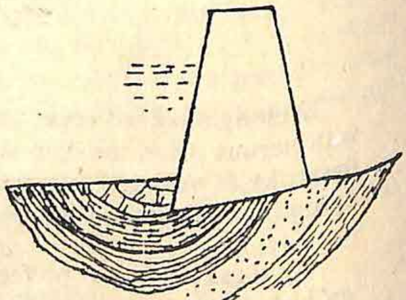


Fig. 107.

axis of crest of the anticlinal fold (fig. 106). But in the case of the synclinal fold the exact axis of the synclinal trough is not so good as the position of the downstream side so as to have beds dipping upstream under the dam site (fig. 107).

Another common source of leakage and danger is the use of porous materials in the dam construction. The floor of the dam on the upstream side should be perfectly water-tight. In hot climatic regions shallow valleys with gentle slopes are not economical as there will be loss of water due to evaporation. An idea of this can be had from the figure shown below :

Let l be the length of water spread.
b the length of dam at the water level
and d the maximum depth of the reservoir.

Volume of water in the reservoir $= \frac{l\ b\ d}{6}$ (approx.)

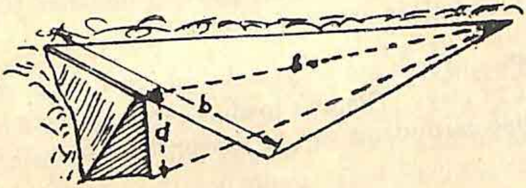


Fig. 108.

If the loss by evaporation is $\frac{1}{10}$ the depth, the new values of l, b, and d are $\frac{9}{10}$ l, $\frac{9}{10}$ b and $\frac{9}{10}$ d respectively.

Therefore new volume $= \frac{1}{6} \left(\frac{9}{10}l \times \frac{9}{10}b \times \frac{9}{10}d\right) = \frac{1}{6} \times \frac{729}{1000}\ l\ b\ d$

i.e. the loss=27.1%.

Similarly, if the evaporation lowers the depth by ¼ then the loss will be 57%. From these calculations, it is evident that shallow valleys with gentle slopes are not suitable.

Faults, joints and fissures can be studied from the surface itself; but sub-surface conditions and other structural features are better known by geological map of the place

Besides the above general considerations, the type of dam to be designed in a given locality is a matter of considerable study. The

principal kinds of dams are Earth or rockfill dams and Masonry or concrete. The latter includes gravity dams, buttress dams and arch dams. The following are the chief considerations :

Gravity dams. These may be constructed on earth foundation if they are of smaller heights. But solid rock foundation is necessary for higher structures.

Buttress dams. These are only modified gravity dams with the volume of concrete reduced by taking advantage of the structural strength of reinforced concrete. They are best suited to regions where construction materials are scarce. These also require good foundations.

Arch dams. An arch has a greater length than a straight gravity section. Hence arch dams are economic only in narrow gorges. Because the abutments must sustain stress caused by the water in the reservoir the additional requirement of strong abutment rock is important. Good foundations are also necessary.

Earth-Dams. These are constructed of loose rock, gravel, sand, silt, rock flour or clay. The unit loading pressure being low and the structure flexible earth-dams can be designed for almost any type of foundation.

TUNNELS

The feasibility of tunnels is dependent upon numerous factors and the geological conditions of the area, that affect the suitability of the rock, are of immediate importance. Geological mapping and structural studies will permit the geologist to predict sub-surface conditions and anticipate difficulties with greater assurance. If sub-surface features are known it is possible to select a safe area for the construction of tunnels.

The ability of the rock to stand cutting and the cost are the chief considerations in the construction of tunnels. The construction is rendered unduly expensive when.

(i) a large volume of water is met with.

(ii) the place is unsuitable for labourers to work due to excessive rock temperature, and

(iii) the rock is charged with harmful or noxious gases, which means loss of life.

Tunnels in loose ground. When a tunnel is driven at shallow epths, i.e., at fifty feet below, there will be constant danger of roof all and also of the sides because of radial pressure. Therefore it is ecessary to take precautions during operation and lining (fig. 109).

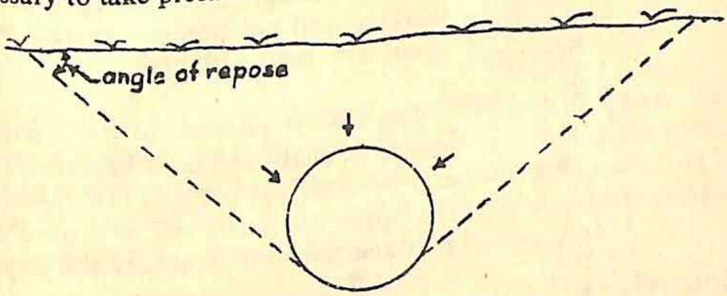


Fig. 109.

In another case the tunnel is driven at a greater depth in loose ground say 100 feet to 200 feet and under such conditions the consolidated material will stand better unless it is heavily soaked with water. Here the pressure on roofs and sides will be less and hence less possibility of rock fall from roofs and sides. However, the tunnel has to be lined throughout (fig. 110).

Conditions of work depend upon the nature of rock types.

Tunnels in igneous rocks. Maximum rock temperature is found here. The deeper the tunnel the higher the temperature. This is overcome by watering or by providing cold blast. Spring water is not generally met with here. Timbering is also not necessary except in few cases and lining may be avoided altogether.

Tunnels in sedimentary rocks. Heavy springs are met with. Hence lining is absolutely necessary. When carbonaceous gases occur they are overcome by a water jet.

Tunnels in metamorphic rocks. The progress of work depends upon the nature of the rocks and their properties like cohesion and hardness.

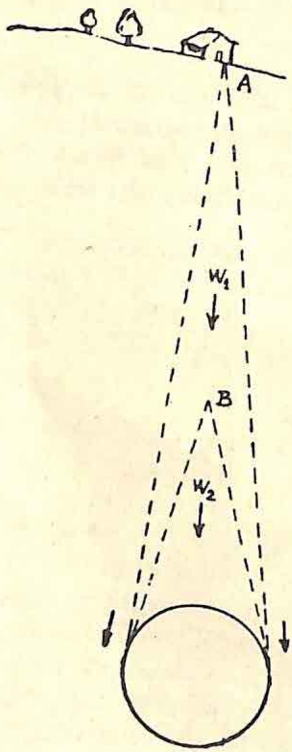


Fig. 110.

Tunnel excavation is easy in consolidated rocks, igneous and metamorphic, e.g., limestone, granite and marble. In the case of stratified sedimentary rocks tunnels should be driven along the strike of beds as the same beds will be met with all along, and the conditions of working will not change. Various conditions are met with here.

The main portion of the tunnel is placed in shale and marl because cutting can be done easily (fig. 113). Moreover the upper sandstone will serve as a good roof and the hard limestone will serve as a good floor.

A tunnel in sandstone in tilted strata is dangerous. If the rocks are dry there is not much of danger, but when water percolates danger prevails (fig. 112).

In thinner sheets one or more beds may be exposed in the tunnel and through these water may find its way. If these laminated strata are steeply inclined there is always the probability of relative movement among the beds and the possibility that the whole length of the tunnel may be subjected to shear stresses, i.e., the displacement of beds (figs. 114 & 115). Therefore in such steeply inclined beds tunnels should not be put

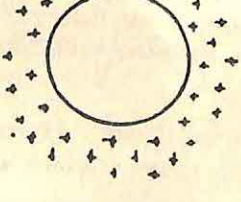


Fig. 111.

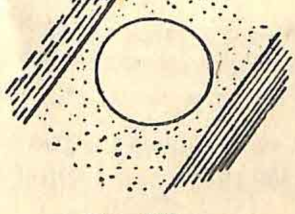


Fig. 112.

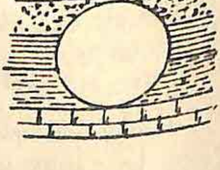


Fig. 113.

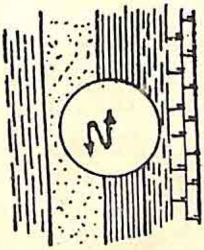


Fig. 114

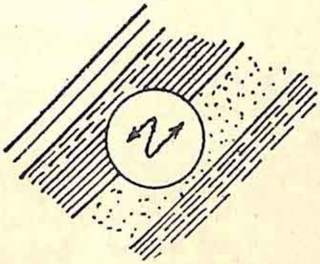


Fig. 115.

in sandstone due to the danger of percolation of water. Secondly tunnels between sandstone and shale is also not good because the sandstone may slip against shale and shut the tunnel. In such a case the best site to drive a tunnel is between shale and marl taking precautions with regard to lining of the tunnel.

Oblique tunnels. When a tunnel is driven across the strike of a tilted strata there is in general, the danger of meeting with water. There is also the danger of one bed sliding relatively to the next bed below and produce shear strain on the cross section of the tunnel.

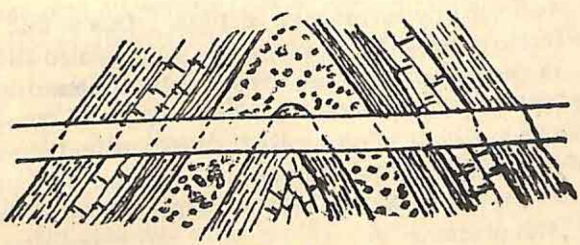


Fig. 116.

Tunnels driven across the anticlinal fold. Roof fall may be expected under the arch of the fold immediately above the tunnel (fig. 116).

Tunnels driven across synclinal fold. There are possible difficulties from water under artesian conditions in the porous beds of the section (fig. 117).

Tunnel section in highly folded rocks. In this case the folds have long limbs. They resemble tunnels driven across the strike of steeply inclined beds (fig. 118) e.g., Long Barog tunnel in Kalka-Simla railway. Tunnel which traverses beds of the Tertiary rocks, obliquely crosses the strike of the steeply inclined beds. These

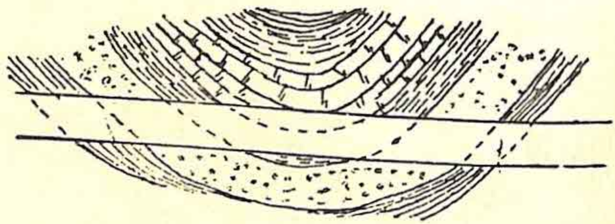


Fig. 117.

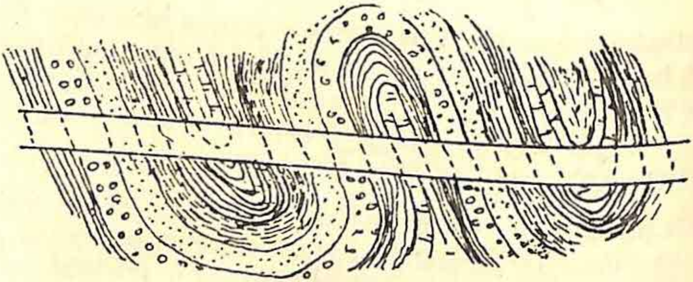


Fig. 118.

beds were unaffected by earthquake of 1903. This is due to the fact that in the Tertiary strata the rocks are less consolidated and the earthquake shocks appear to have been absorbed or deadened by a kind of cushioning action. The presence of faults may add considerably to the difficulty and expense of excavation. Lines of faulting which cross the line of tunnel are frequent sources of springs, particularly when porous beds on one side dip towards the impervious rock on the other side of the fault plane.

Ventilation of tunnels. Harmful effects of gases in tunnels can generally be minimised by a proper system of ventilation and use of compressed air employed for driving the machinery used in the tunnel. Simplest method of ventilating a tunnel is to have numerous wide openings to daylight at frequent intervals.

Pressure tunnels. The question of water in tunnels depends greatly on the porosity of rocks and the extent of outcrops, that is, the surface exposed as a catchment for the absorption of rain water. The structure of tunnel constructed for conveying water through a hill or ridge has to be considered with regard to leakage and possible damage for mines or properties in the neighbourhood

LANDSLIDES

Landslides occur when, by natural process, the unconsolidated loose material or the jointed mass of a hillside detaches itself from the hill and slides down the slope. The loose material on all the hill slopes tends to slide or creep down the hill if the hill slope exceeds the angle of repose of the materials. These conditions arise from natural causes like weathering, rain and in cold countries due to frost action. This may also be due to overgrazing of land by cattle and deforestation. Underground water is also one of the chief agents for causing landslides The percolating water lubricates the under surface and produces slumping and slipping. Landslides are also caused by earthquakes and erosion.

Surface creep or *soil creep* can be prevented to a certain extent by vegetation and artifical means (concrete lining). Grass and tree roots generally not only bind the soil and subsoil as a mat but by preserving more constant moisture content reduce the volume changes associated with alternate wetting and drying of the surface soil.

Stability of hill slopes. This depends largely upon the nature of parting and joint planes and also geological structures with regard to bedding planes and folding.

In bedded strata there is always a tendency of beds to slide over the bedding (Fig. 119). Tendency of sliding is so strong on these slopes that a drag or pull is exerted on the beds below by the surface soil overlying it. As a result, the beds are bent in the direction towards the foot of the hill. This action of terminal creep induces conditions which give rise to larger landslides.

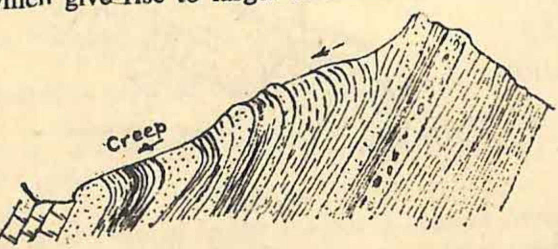


Fig. 119.

Landslides are liable to occur on hill slopes where dip of the bed is also in the same direction (Fig. 120). If the rocks dip into the

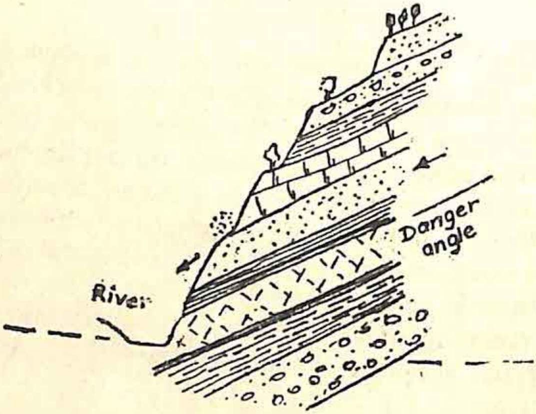


Fig. 120.

hill there is no fear of slips unless there occurs a system of joints whose planes are along the slope of the hill and thus function as bedding planes (Fig. 121). The most dangerous hillsides are therefore those which slope over 40 degrees and composed of hard and soft rock beds.

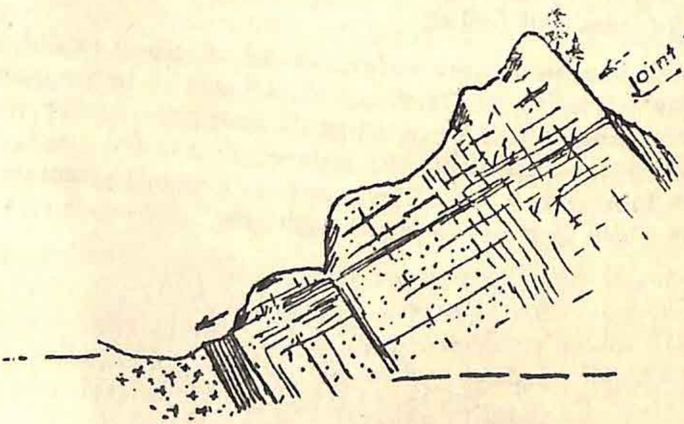


Fig. 121.

A general rule can be given for the location of a road along a valley with steep slopes. Avoid as far as possible the side of the valley in which the rocks dip towards the stream. This precaution is especially necessary when alternate layers of hard and soft beds occur

SOIL EROSION

Soil erosion is one of the serious problems confronted by the agriculturists tc-day in many parts. Soil is an irreplaceable resource. It is formed due to the action of atmospheric weathering. Soil erosion is the loosening of the soil from the bed and the transportation of soil material from one place to another. This takes place through the action of wind or water in motion.

Erosion due to water is the most serious and extensive type that occur in many parts of the Madras and Andhra States notably in the coastal districts, e.g., the black soil areas of the Cuddapah and Kurnool districts, Coimbatore and the hilly tracts of Nilgiris. The two fundamental types of water erosion are *sheet erosion* and *gulleying*. They cut up agricultural lands into small fragments and make them unfit for cultivation in course of time.

Soil erosion is one of the consequences of deforestation which also causes failure of rainfall. The day temperature within a forest is lower than outside, but when the trees disappear the sun heats up the rocks and bare earth, with the result, the hot air rises and forces up the clouds which no longer drop their moisture in the form of rain and the country becomes drier than when it was covered with forest.

Remedies. "Nature to be commanded must be obeyed". We should work in accordance with laws of Nature. Under natural undisturbed conditions an equilibrium will be established between the climate of the place and that of the cover of vegetation that protects the soil layer. Vegetation, trees and forests retard the transportation of soil material and act as a check against excessive erosion. Some of the remedies followed are :—

1. Afforestation as in the Jumna ravine lands in the Uttar Pradesh.

2. Terracing and drainage of sloping bed as in the tea estates of Assam and Nilgiris.

3. Bunding of fields as in the Bijapur district of Mysore.

4. Crop rotation, that is, recurrent succession of different crops on single land.

5. Application of green manure to the fields and
6. Proper control over graze lands.

GEOLOGY OF SOILS

Introduction. Soil the thin cover that occurs on the surface of the earth is of great importance to all living beings. The word soil is popularly used to denote the loose material constituting the surface of the earth in which plant grows. Soil is an irreplaceable resource. Nature takes under most favourable conditions 200 to 1000 years or more to build a single inch of top soil from the raw materials of the sub-soil depending upon the climatic conditions and nature of the sub-soil material.

If the top soil is lost the land will be deprived of its fertility and in turn it will affect the prosperity and well being of all living beings existing over it. So the conservation of this natural material is of utmost importance. Soil erosion takes place through the action of wind or water in motion. One of the chief causes for this is deforestation. The vegetation, trees and forests retard the transport of soil material and act as a check against excessive erosion. It should be borne in mind that while laying highways, railways and planning townships, the vegetation which forms the protective blanket for the loose soil on the surface of the earth should not be removed unscrupulously. Hence the Governments have constituted the soil conservation board to see that the top soil on land is well protected. The soil constitute the natural surface of the earth that is encountered in many civil engineering operations. In engineering, the term soil includes loose material as well as the unconsolidated earth materials that occur below the loose soil. Commonly an engineer is concerned with depths of 50 or less in his construction works. Soil occurring in this layer is responsible for many difficulties faced during construction and also after completion. The stability of the structures greatly depend on the behaviour of the soil. A well known example may be cited i.e., the leaning tower of Pisa in Italy. This tower is 179 ft., in height and leans 16 ft. out of the perpendicular. This is due to settlement of underlying alluvial soil which resulted in tipping of the structure.

Soil study related to Civil Engineering gained importance only in recent years

Soil Genesis. The knowledge of soil genesis and occurrence is useful in the study of the properties of the various kinds of soils and their correlation. So the various processes responsible for soil formation and their occurrence should be generally familiar. Soil is found in the boundary zone of lithosphere and atmosphere. It is formed due to processes of interaction of the two. Soils occur as products of rock destruction. The process of change resulting from exposure of rocks to the influence of atmosphere is known as weathering. Weathering can be divided into two subprocesses —disintegration and decomposition.

Disintegration may be called mechanical weathering and it is brought about by the following conditions : 1. Temperature changes. 2. Freezing and thawing. 3. Action of plants and animals. Decomposition may be described as chemical weathering and it is produced by chemical changes, such as (i) Oxidation. (ii) Hydration. (iii) Carbonation. (iv) The effects of organic acids derived from vegetation. The action of these weathering processes is gently influenced by the climatic conditions. It is observed that the rocks are weathered predominantly by decomposition in warm humid climate; by disintegration in warm dry climate; by combination of the above two in temperate climates and by expansion and contraction of ice in cold regions.

Depending upon the resistance to mechanical and chemical weathering minerals get altered. Important rock forming minerals and their altered products are as follows :—

ROCK FORMING MINERALS	ALTERED PRODUCTS OF WEATHERING
Quartz	Reduces in size but retains identity
Felspars	Clay minerals and soluble matter
Mica	Clay minerals-hydrous silicates
Hornblende, Augite	Hydrous silicates
Olivine	Serpentine and iron oxide

In this process of alteration the formation of clay minerals is important.

The rate of weathering is greatly dependent on the type of rocks exposed. The geological formations differ from place to place and they are of varied character—Igneous, sedimentary and metamorphic.

As a result, soils found on the earth's surface vary greatly. There are many kinds of soils.

Classification of Soils. There are various classifications. Geological Classification is based on the mode of formation. They are :

1. Residual Soils. 2. Transported Soils.

Residual Soils. These are formed as products of weathering and are usually formed where natural rock surface is approximately horizontal. Here the chemical composition of the soil cover and the bed rock is almost identical.

Transported Soils. These are formed from weathered material transported by the various agents such as wind, water, ice etc. They are described as given below after the agency of transportation or mode of origin.

KIND OF SOIL	THE CHIEF AGENCY OF TRANSPORTATION OR MODE OF ORIGIN
Aeolian Soil	Wind
Alluvial Soil	Streams & rivers
Glacial Soil	Glaciers
Lacustrine Soil	Lake
Marine Soil	Coastal
Colluvial	Gravity
Volcanic	Volcanic action

There is a broad classification adopted by American and Russian pedologists. These groups include the soils having similar internal characteristics. They are Tundra Soils, Desert Soils, Podsols, Prairie Soils, Chernozem Soils and Laterite Soils.

Soil Components. Soils are composed of solids, liquids and gaseous components. Soil minerals and organic matter constitute the solid part and the water and air in the interstices between the solid particles form the liquid and gaseous components respectively, the latter two fluctuate frequently. The mineral constituents are extremely variable in size, shape and chemical composition. The properties such as water absorption, air movements, rate of solution and ease of tillage are dependent on the particle size.

In the study of properties of soils, the particle size of the soil material is significant. Hence the particle size is the basis of cla: cation in Engineering. In Engineering practice there are standard methods of mechanical soil analysis by means of sieves, elutriators and hydrometers. The various laboratory tests on soils are determination of moisture content, plastic and liquid limits, shearing strength, consolidation under load, penetration test, permeability test etc. A knowledge of local geology is necessary to make sure that the type of soil encountered in the area is same throughout. Then only the test results obtained on soil samples may be applied to design work safely.

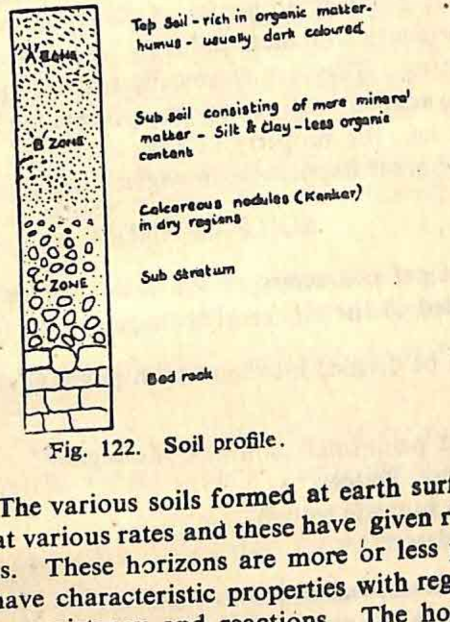


Fig. 122. Soil profile.

Soil Profile. The various soils formed at earth surface are continuously changing at various rates and these have given rise to different layers or horizons. These horizons are more or less parallel to the surface. These have characteristic properties with regard to colour, texture, porosity, consistency and reactions. The horizons may be thick or thin. The succession of horizons is called the soil profile. These horizons in the soil profile are designated by the letters A, B, C. The surface horizon forming the top soil is the 'A' horizon. It is underlain by the sub soil 'B' horizon. The zone under 'B' having the substratum is the 'C' horizon. To the engineer the soil profile is a cross section of an actual soil-deposit from the earth surface to the depths which he considers for his purpose. If this cross section reaches into the underlying rock the term geological section is used.

The two great names associated in the pioneering and tremendous

work done in soil study are Dr. Karl Von Terzaghi and Dr. A. Cassagrande. The soil study has given rise to another specialised branch of study namely Clay mineralogy. The outstanding work in this field has been done by Prof. Ralp. E. Grim.

Study of Clay minerals is of very recent origin. Because of fine grained nature and the intimately mixed composition of the materials, great difficulty is experienced in the study of these minerals. These clay minerals may generally be classified under three groups.

1. Kaolinite 2. Montmorillonite 3. Illite or hydromicas. Many of the peculiar physical properties of clays are now known to be due to the properties of these minerals, especially those relating to moisture content. They are chemically reactive (particularly groups 2 and 3) being acidic in nature and they possess the important absorptive property i.e., the property of base exchange. These properties prove to be of great importance in engineering construction.

SOILS OF INDIA

The principal characters of the main soil groups of India are generally related to the nature of their geological foundations.

India can be divided into four main physical and geological divisions.

(1) Extra peninsular mountainous region
(2) Deccan Plateau
(3) Indo gangetic trough
(4) Thar desert

Extra-peninsular mountainous region. The site of the Himalayas was under the sea during the whole of Palaeozoic and Mesozoic periods in the earth's history. It was only in the beginning of Tertiary the Himalayas began to be upheaved. Himalayas is one of the broadest, longest, highest mountains. The rivers in the Himalayan region are very young and in mature stage cutting their channels very rapidly in contrast to old rivers of peninsular India which has reached their base-level of erosion. The region being mountainous the soils can be accumulated only in favourable regions.

Deccan Plateau. With regard to elevation of the plateau it varies from 1500 ft to 2500 ft, although there are peaks to an altitude of 8000

ft. We have relict type of mountains which withstood the wear and tear of the denudation. The western ghats and the eastern ghats are the examples. Various type of rocks are found in this region—Granites, Gneisses and Basalts. Granites and Gneisses give rise to red soils by weathering and decaying. There are basic gneisses which give rise to dark soil—practically comparable to 'black cotton soil'. The great basalts formed due to eruptions of lava during the close of Mesozoic and beginning of the Tertiary era give rise to fertile black cotton soil. The rivers Mahanadi, Godavari, Krishna and Kaveri have developed deltas in the east coast.

Indo–Gangetic Trough. This is formed as a depression between Himalayas and Deccan Traps and then filled by the sediments brought by the rivers from the mountainous areas lying behind. This region constitutes the rich alluvial plains of the Indian region.

Thar Desert. Practically the whole of Rajasthan and adjoining areas is composed of parallel ridges. Wind blown sand is formed in between them in the intervening valleys.

Climatic Factor. In India major portion enjoys Monsoon climate. This is a very important factor in the development of soils.

The Main Soil Groups of India. Soils are of two types—Transported and Residual.

Transported or drift type of soils. Formed by running water, wind or ice e.g., soils of Indo-gangetic plains and coastal areas of Peninsular India.

Residual or in situ soils. e.g., Soils of Peninsular region and Himalayan region.

General Characteristics of Indian Soils

The soils of the Indian peninsula show marked contrast to soils of European countries. The European soils have close affinities with their rocky substratum. Podsolisation is a common character of these soils. Some mountain and forest soils of north India can be compared to podsol soils

The alluvial soils of the vast Indo-Gangetic plains have been deposited geologically in sub-recent times. These differ from peninsular soils and majority of European soils in having undergone but

little pedogenic evolution. They are still largely immature and do not show any characteristic soil profile or differentiation into zones.

The following are the important kinds of soils : (1) Red Soils (2) Black Cotton Soils (3) Lateritic soils (4) Alkaline soils (5) Mountain and Forest soils (6) Alluvial soils.

Red Soils. They occur over an area of 800,000 sq. miles including parts of Bihar, Bengal, Orissa, parts of Madhya pradesh, Andhra, Mysore and major part of Tamil Nadu. The colour of these soils is generally red, often grading into brown, chocolate, yellow, grey or even black. The colour is due to oxidation and wide diffusion of the iron content. It is moderately fertile and varies considerably in composition because of the variation in characters of the original rock. The red soil group is generally deficient in its content of soluble exchangeable bases and their total base exchange capacity for K, Ca, etc. is generally low.

Black Cotton Soils. This is also known as Regur and is the equivalent of the Russian Chernozem. This covers a large area of Gujarat, Maharashtra, MadhyaPradeshand Andhra. Isolated patches of Regur, though less,typical also occur in Tamil Nadu.

The most characteristic black soils cap the volcanic plateau of the Deccan Traps forming a mantle of rich residual soil.

In Deccan trap country, it is observed the soil is red or brown, the colour of the soil is more reddish or brownish than blackish as seen in Jubbulpore. Typical black soil is highly argillaceous, highly porous, swells enormously when wetted and dries up with conspicuous cracks. The dense black colour of these soils is due to varied reasons. Partly it may be due to iron or to some minute quantity of a titanium-iron compound and partly to carbon and organic matter. The base exchange capacity of regur is fairly high.

Lateritic Soils. This soil group forms a belt of variable width round the peninsula. It occurs mostly in Tamil Nadu, Kerala, Maharashtra, west of Mysore, Orissa and Bengal.

In lateritic soils leaching action is complete. So there is a concentration of hydroxide of alumina and iron with the loss of silica, lime magnesia and alkalies. Because of the intensive leaching and the low base-exchange capacity the lateritic soils are lacking in fertility and are of little value for crop production.

Alkaline Soils (Reh, Usar, Kalar Soils). These are salt impregnated or alkaline soils which form a peculiar group in India. Soils on the drier parts of North Bihar, Uttar Pradesh, Punjab and Rajasthan tend to saline and alkaline efflorescences. Such lands are known as reh in the Uttar Pradesh, Kalar in Punjab and Chopan in Bombay.

Mountain and Forest Soils of the Himalayan Region. These soils are found in the depressions in valley basins and on the less steeply inclined slopes. These are primary soils, shallow, immature, containing a large proportion of undecomposed mineral grains. They are sandy or gravelly, porous, devoid of humus and frequently impregnated with lime and soda salts.

Alluvial Soils. The alluvial soils are the most important from the agricultural point of view. They form rich loamy soils and are highly fertile. They cover the greater part of North India between the foot of the Himalayas and the northern slopes of the Vindhyas and extend in a narrow fringe round the coast line of the peninsula. They occupy the parts of Punjab, Rajasthan, Delhi, Uttar Pradesh, Bihar, Bengal, Assam, Coastal districts of Andhra and Tamil Nadu. They are deficient in phosphoric acid, Nitrogen and humus but adequate in potash and soda.

QUESTIONS

1. Describe and classify building stones. Explain how their durability is ascertained.

2. What are the essential qualities of a good building stone? What physical tests will you carry out before deciding whether a particular rock is suitable for building purpose or not ?

3. Classify the building stones and give a description of the physical properties of a durable variety. What are "injurious" minerals and how do they shorten the life of a building stone ?

4. Give an account of the physical properties that go to make a good building stone. Draw a sketch map of Peninsular India and mark therein the important localities of occurrences of building stones, mentioning the salient features of each variety.

5. Name and fully describe the physical properties of any four

of the important rock types that are used as building stones. Where and in what geological formations do they occur in India.

6. What are the principles that govern economic quarrying and selection of quarry sites? Explain with reference to any quarry which you have visited.

7. What are the principles which govern the economic quarrying of stones and selection of quarrying sites? Illustrate your answers by methods followed in quarrying standstones, granites and slates.

8. Define (*a*) Water table (*b*) Aquifer (*c*) Permeability of a rock. What are the geological factors which you will consider in selecting a site for a well in an area occupied by (*i*) Stratified rocks (*ii*) Crystalline rocks.

9. What is meant by "ground water"? How is it surveyed and explored? Describe the condition when the underground water is lifted to the surface by its own pressure.

10. Give an account of the origin, occurrence and circulation of ground water. Examine the possibilities of augmenting the water supply position in Madras City.

11. How does a tube well differ from an artesian well? What are the geological factors which you will consider in selecting a site for a tube well and an artesian well? Indicate the regions in India which are suitable for putting one or the other type of these wells.

12. Briefly explain how you will survey the underground water resources of any city with water supply from other sources. To what extent can such a ground water supply be made to augment the existing supply?

13. What are the geological factors which influence the choice of site for a reservoir? Discuss the suitability of various geological structures and rock types of reservoirs.

14. What are the artificial lakes? Give an account of the Geological factors that influence their location. Illustrate your answers with reference to any artificial lake you have seen.

15. What is "River valley project"? Give an account of the

suitable geological conditions for the proper execution of such a project.

16. "An earth dam carefully designed and built will prove as permanent as any of the works of man, if proper attention is given to important details during construction". Explain geological and related criteria implied in the above statement.

17. What are the geological requirements which will have to be investigated for selecting a site for a tunnel. What type of lining would you suggest for tunnels driven in (*a*) Unconsolidated (*b*) Consolidated rocks.

18. Explain briefly the distinction between :—
Landslide and creep.

19. Write short geological notes on :—
Landslides, Artesian well.

20. Discuss the geological factors which affect the stability of hill sides. What precautions will you take against the natural changes to which roads on hill station are subjected as a consequence of the action of geological agencies ?

21. Write a short essay on the utilisation aspect of geology in engineering.

(see also appendix)

ECONOMIC GEOLOGY

Mineral Deposits. The term mineral deposit designates an occurrence of one or more minerals in such concentration as to form a deposit of economic value. Mineral deposits fall naturally into two classes; metallic and non-metallic.

An ore is a mineral aggregate from which one or more metals can be extracted at a profit. It consists of one or more metalliferous minerals associated with worthless mineral or rock matter known as *gangue*.

Forms of Ore Bodies. The shape and form of an ore body is of great practical importance, for it determines the way in which the ore body can be worked. A tabular mass of ore more or less sharply defined from the rock is termed a *vein*. During the formation of such mineral veins some irregular openings or cavities are formed and they are known as *vugs* or *druses*. A *lode* consists of several veins spaced closely enough so that all of them together with the intervening rock can be mined as a unit.

Kinds of Ore Deposits. A feature that distinguishes most mineral deposits from other geological formations is that they contain useful minerals in relatively concentrated form and in large quantities. Mineral deposits are classified after the geological processes that brought about the concentration.

1. Concentration by igneous activity.

(*a*) By magmatic concentration, e.g., chromite.

(*b*) By hydrothermal solution, e.g., Veins of copper, gold and tin. Replacement deposits of lead and zinc, some deposits of copper.

2. Concentration by weathering, e.g., Bauxite, iron ores, some copper ores.

3. Concentration by sedimentary processes.

(*a*) By mechanical sorting e.g., Placer deposits of gold and tin.

(*b*) By chemical precipitation, e.g., Rock salt and gypsum, iron ores.

(*c*) By organisms, e.g., Coal and petroleum.

Concentration by Igneous Activity

Magmatic concentration. Certain accessory or uncommon minerals of magmas may become concentrated into bodies of sufficient size and richness to constitute valuable deposits as a result of simple crystallisation or from concentration by differentiation of intrusive igneous masses

Definite associations exist between specific magmatic ores and certain kinds of rocks. Most of the rich mineral deposits occur in association with deep-seated basic igneous rocks like norite, peridotite, anorthosite and gabbro, e.g., platinum, chromite, nickel, copper and diamond.

During the progressive crystallisation of the magma, the abstraction of the early crystallising rock minerals leaves a residual liquid, generally *silicic*, which gradually becomes enriched in volatiles and gases. These residual liquids also contain compounds of metals and other valuable substances in concentrated form and they result in the formation of *pegmatite* rock with its rich mineral deposits under favourable conditions.

Hydrothermal solutions. During the final crystallisation of the magma, residual aqueous solutions are ejected in the form of gases or liquids or both, which move upwards towards places of less pressure. These hot ascending magmatic solutions are known as hydrothermal solutions and they are responsible for deposition of certain minerals.

The deposits are classified into three groups according to their mode of formation.

CLASSIFICATION OF HYDROTHERMAL DEPOSITS

Kind of deposit	Mode of formation	Chief ores formed
Hypothermal	Formed at great depth at high pressure and temperature	Cassiterite, Wolframite, Molybdenite, Gold-quartz veins, copper-tourmaline and lead-tourmaline
Mesothermal	Formed at intermediate depths at high pressure and temperature	Pyrite, chalcopyrite, aresnopyrite, galena, sphalerite and native gold
Epithermal	Formed at low depth under moderate pressure and temperature	Native, gold marcasite, pyrite, cinnabar and stibnite

Replacement deposits. Replacement may be defined as a process of simultaneous capillary solution and deposition by which a new mineral is substituted for one or more earlier formed minerals. These deposits are also known as *metasomatic* deposits and this process of replacement is *metasomatism*. The ore minerals of contact-metamorphic deposits have been formed almost entirely by this process. The chief ores are iron, copper, lead, gold, silver, tin, mercury, manganese, barite, magnesite, fluorite and kyanite. By means of replacement wood may be transformed to silica (petrification); a single mineral may take the place of another retaining its form and size (pseudomorphs); or a large body of solid ore may take the place of an equal volume of rocks.

Concentration by Weathering

Under warm humid climate most rocks react to weathering and many of their constituents are removed either in solution or mechanically, e.g., bauxite ore, oxide of iron and manganese.

Secondary or supergene enrichment. When ore deposits become exposed by erosion they are weathered along with the enclosing

rocks. The surface waters oxidise many ore minerals and yield solvents that dissolve other minerals and carry them downwards to the ground water-table. When solutions penetrate the water-table, their metallic content may be precpitated in the form of secondary sulphides to give rise to a zone of secondary or supergene enrichment. Rich iron ore and copper deposits are formed due to these processes of oxidation and secondary enrichment. The occurrence of this kind of deposits are often indicated by the outcrop of yellow rusty limonitic deposits. These are termed gossan (meaning iron hat) or caprock.

Concentration by Sedimentary Processes

Placer Deposits. When weathered materials are transported by moving water or air, the heavier materials tend to accumulate in the basins of the channel. Such a deposit of heavy minerals is called a placer. Concentration of this kind can occur only if the valuable minerals possess the three properties, viz., high specific gravity, chemical resistance to weathering and durability, e.g., Gold, platinum, tinstone, magnetite, chromite, ilmenite, native copper, gemstones, zircon, monazite, phosphate, quartz and quick silver.

Rich deposits of salt and gypsum in sedimentary rocks are formed as a result of evaporation and precipitation of salts in ancient sea basins and lake basins.

Mineral deposits of organic origin are coal and petroleum.

Coal. Coal occurs in Nature as the remains of plants which have preserved solar energy of geological past for the use of Man. It first originated in swamps and passed through a peat stage. The favourable conditions for the accumulation of coal are mild temperature to sub-tropical climate and moderate to heavy rainfall well distributed throughout the year. Various types of coal are formed according as environment, kinds of plants and nature and duration of bacterial action and degree of metamorphism during the formation. Coal beds occur as flat lenses within "coal measures" which consist of alternating beds of sandstone, shale and clay, mostly of fresh water origin. The thickness of coal seams ranges from a mere film upto 600 feet. Coal seams contain partings or thin bands of shale or clay, exhibiting the structural features of sedimentary rocks.

Rich coal deposits of the world belong to the Carboniferous and Tertiary periods. The coal deposits of the latter period is mostly of lignitic variety.

Petroleum. It is one of the important fuels of the 20th century and has become a necessity of modern civilisation.

Origin. The oil and gas are of organic origin. The organic material buried in marine beds underwent changes to produce natural hydrocarbons and these subsequently moved into reservoir rocks and accumulated to form oil pools.

Sources. The slow decomposition in the absence of oxygen of the remains of plant and animal organisms is responsible for the formation of petroleum hydrocarbons. The lower planktonic organisms such as diatoms and algae that thrive abundantly near the surface of the sea are the most probable and important of the sources, the higher forms of life on land being unimportant.

During the conversion of organic matter into petroleum, natural gas, dominantly methane is also formed.

The conditions necessary for the formation of an oil pool which is merely an accumulation of petroleum in rock pores and not a subterranean pond are :

(1) Migration and accumulation, (2) Suitable reservoir and cap-rocks, (3) Suitable traps and (4) Retention.

Migration of oil generally results in accumulation of oil droplets into oil pools. Migration may not result accumulation or it may result accumulations of non-commercial bodies as at the top of horizontal beds, but concentrated accumulation is essential to produce commercial pools and this in turn is dependent upon requisite reservoir rocks and traps.

Reservoir rocks. Accumulation can take place only in porous and permeable rocks. The greater the porosity the greater the accumulation of oil and the larger the pore size the greater will be the yield. A rock like clay with high porosity and low permeability is not a suitable reservoir rock. The most suitable reservoir rocks are sands, sandstones, porous or cavernous limestones, rarely fissured shales and jointed igneous rocks.

Caprocks. A confining impervious caprock retains oil in a reservoir rock. The most common caprocks are shale, clay, dense limesone, gypsum well cemented fine grained sandstones and shaly sandsone.

Traps and structures. In inclined sedimentary beds, the upward migration of oil pool will continue until it escapes at the surface or is arrested in some trap where it forms an oil pool. If the beds are folded into an anticline, upward migration ceases when the oil reaches the top of the arch where it forms an anticlinal pool. This is the most common kind of trap. The greater part of the oil so far produced is from anticlines and domes. In an elongated anticline the extended flanks facilitate migration, the arch permits accumulation and the crest containing dome-like areas collects oil from all sides, which is retained beneath the caprock. Therefore it serves as an ideal petroleum trap.

Many oil pools have resulted from faulting, a thick fault rarely serving as an effective upward seal to an oil sand.

Igneous instrusions in the form of volcanic necks, dykes and sills have similarly upturned and sealed petroliferous beds to form oil traps.

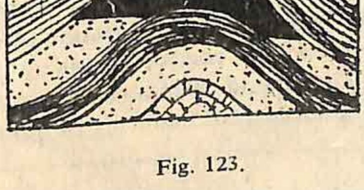


Fig. 123.



Fig. 124.

Another interesting structural trap for oils is *salt dome.* They are formed as a result of salt flow upwards, bending the overlying strata above to make oil traps. Under pressure, the yielding plastic salt was forced upwards along some lines of weakness such as fault

intersections. These are also known as *salt plugs* and they consists of salt, anhydrite and calcite.

Due to metamorphism several kinds of non-metallic minerals are formed. The chief deposits are asbestos, graphite, talc, soapstone, andalusite, sillimanite, kyanite and garnet.

Prospecting of Mineral Deposits. Prospecting has become more difficult as the easily discoverable mineral deposits have already been found. With the advancement of science different scientific instruments have been brought into use in the search for mineral deposits hidden in the earth's crust. The various geophysical methods in use are as follows :

1. *Magnetic method.* This method utilises the principle that the compass needle is controlled by the earth's magnetic field in the vertical and horizontal planes. Magnetic surveys are made with horizontal and vertical dip needles along parallel lines and readings are taken at specific intervals. The position of attracting bodies is indicated by the apparent increase or decrease in the earth's magnetic field. This method is useful only for substances that exhibit magnetic property, e.g., magnetic iron ore, pyrrhotite, nickel and cobalt.

2. *Electrical method.* Electrical methods are used in the search for metallic mineral deposits and oil, for sub-surface exploration and in electrical logging wells. These methods are based upon the low specific electrical resistance of metallic minerals.

3. *Electro-magnetic methods.* These are preferred to other electrical methods in the search for ore bodies. These methods utilise the principle that a current passing through a conductor sets up a magnetic field around the conductor. The secondary induced current set up by an ore body lying within the induced field indicates its presence.

4. *Gravity methods.* In these methods the principle of gravitational attraction is made use of and the devices employed for measuring gravitational attraction are: (1) the pendulum whose period of oscillation is dependent on earth's gravitation which in turn depends on the density of rock beneath the surface, (2) the torsion balance in

which the deflection of a graduated fine wire measures the gravitational pull of buried mass, and (3) the gravimeter in which gravity is compared with an elastic spring force at different places. The latter two are employed in petroleum prospecting.

5. *Seismic methods.* The earthquake waves travel at different velocities through materials having different densities. By measuring the velocity of waves produced by artificial earthquakes using explosives, ore bodies are detected.

These methods are also employed for determining the depth of bed rock for foundations of bridges, dams and buildings and for determining the nature of the material to be excavated.

MINERALS IN INDUSTRY

Minerals form the invaluable raw materials in different industries. They form the backbone of modern industrial life. The various uses of minerals are given below

Metal Industry

Metal extracted	Ores used
Iron	Hematite, magnetite, limonite, siderite, and marcasite.
Iron alloys	Psilomalane, pyrolusite, braunite, cobaltite, molybdenite, ilmenite, rutile, scheelite, vanadiferous **magnetite** and chromite.
Copper	Chalcopyrite, cuprite, native copper, chalcocite, malachite and azurite.
Lead	Galena and cerussite.
Aluminium	Bauxite and cryolite.

Other Industries

Fuels. Coal (peat, lignite, anthracite) and petroleum.

Refractories. Fire-clay, kaolin, kyanite, sillimanite, magnesite, andalusite, graphite and chromite.

Abrasives. Diamond (bort), corundum, emery, garnet and red ochre (rouge).

Paints. Hematite, ochres, barite, ilmenite, chromite, celestite, graphite and lead ores.

Cement. Limestone, clays, gypsum, bauxite, asbestos and magnesite.

Glass. Quartz, felspar and kyanite,

Ceramics. Kaolin or China clay, felspar, talc, gypsum and milky quartz.

Insulators. Asbestos, mica and magnesite.

Paper and rubber. Kaolin, barite, gypsum, mica, sulphur and salt.

Fertilisers. Gypsum, apatite and phosphate rock.

Optical and scientific instruments. Calcite (Iceland spar), fluorite, gypsum, agate, quartz, mica and tourmaline.

Gemstones. Diamond, garnet, topaz, corundum, beryl, olivine and amethyst.

Strategic minerals. (essential for National Defence) Coal, petroleum, sulphur, beryl and ores of tin, iron, lead copper, aluminium, titanium and uranium.

Radioactive minerals. Pitchblende and monazite.

Refractories. Modern high temperature metallurgical furnaces require refractory materials for furnace linings that will withstand high temperatures (about more than 1500°C). They are also required for high temperature purposes in retorts, for electrical purpose and for ceramics.

Essential qualities for good refractory materials are :—

1. It should withstand high temperatures.
2. It should not react with molten materials.
3. It should be strong enough to withstand the weight and wear of molten metals and slag.
4. It should resist cracking and spalling under temperature changes.
5. It should be easily moulded into bricks or other forms.

The common refractories are generally grouped as follows :—

Fire clays. Kaolin and fire clay.

Silica. Quartz and diatomite.

Alumina. Bauxite, corundum, kyanite and sillimanite.

Magnesite. Magnesite and dolomite.

Chrome. Chromite.

Others. Graphite, beryl and zircon.

Abrasives. Many minerals and rocks are used as natural abrasives. Artificial abrasives are also made from mineral products.

Natural abrasives are divided into 3 groups.

1. *High grade natural abrasives* which include in the order of ardness diamond, corundum, emery and garnet.

2. *Siliceous abrasives* which include various forms of silica, quartz, pumice, sandstone, quartzite and diatomite.

3. *Miscellaneous abrasives* which include buffing and polishing powders, bauxite, magnesite, chalk, lime, China clay, talc and carborundum.

Abrasives are widely used in all phases of industry, the automobile industry being the largest user.

QUESTIONS

1. Where in what form and what geological formations do the following minerals occur in India and what are their economic uses ?

Monazite, Chromite, Magnesite, Gypsum, Diamond, Corundum, Lignite, Asbestos, Bauxite, Barite, Psilomelane, Beryl, Kyanite, Kaolin, Mica, Pyrolusite, Garnet. Ilmenite, Apatite, Felspar, Ochre, Hematite.

2. Enumerate the common types of Refractories used in modern industries. Give one example in each type and describe their mineral composition and special properties.

Write short notes on the following :

Replacement deposit, Secondary enrichment, Gangue, Placer deposit, Salt dome, Gossan, Vein.

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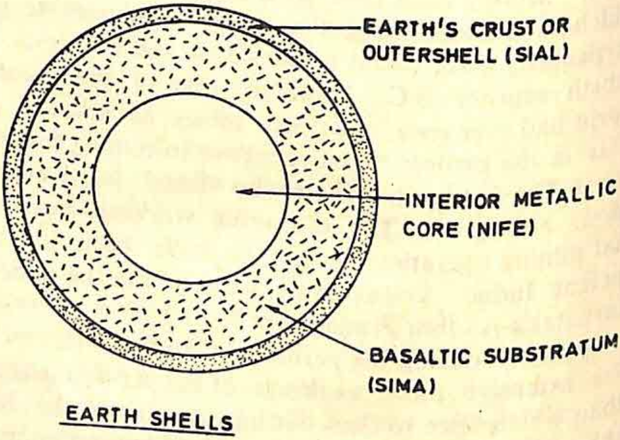
CHAPTER III : MINERALOGY

Introduction : Minerals form the backbone of modern industrial life, as they provide raw materia for almost all the industries. All minerals and mineral products are derived from rocks forming the crust of the earth. The past of our country owes its glory to the invaluable minerals. Before the advent of the Christian Era, people in India were skilled in metallurgy and the manufacture of weapons. Valmiki, in his 'Ramayana' describes Chitrakuta (Ayodhya Kanta-Sarga 94) as a region full of rich minerals. In 'Silappathikaram', one of the five great epics in the Tamil literature, Kovalan, the hero, praises Kannaki, the heroine, as a gem not obtained from mountains. Mining must have gone on in India from prehistoric times which is evident from the many references to jewels and metals, particularly gold, found in the Vedas and the Epics. As early as the fourth century B C., Kautilya, one of the greatest diplomats the world had ever seen, described 'mines as sources of the treasury'. This is the earliest direct reference to mining found in Indian literature. The foreign travellers who visited India found it a land of jewels and gold. The old mine workings bear witness to the fact that mining operations ought to have been in full swing in the ancient India. For example, we may cite the mines at Hutti, on the Karnataka-Andhra Pradesh border, which is understood to have been in operation during the period of the great Maurya Emperor, Asoka. The extensive mine workings of copper deposits at Khetri in Rajasthan which were worked during the reign of the Mughal Monarch, Akbar the Great, and the Golconda diamond mines of Vajrakarur in Kurnool District (Andhra Pradesh) are considered to have been in existence from very early times. The world-famous Kohinoor diamond, which now adorns the British Crown, was obtained from the Golconda Mines.

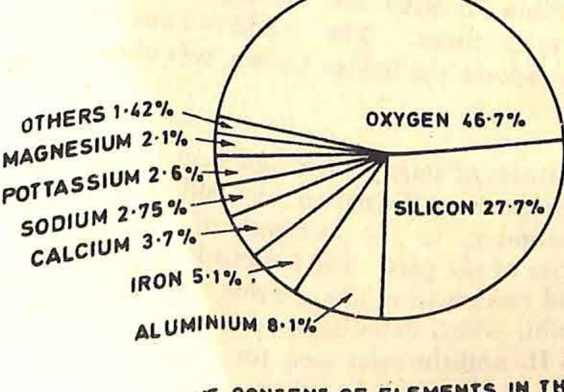
The immense quantities of slags of iron and steel and metals like copper, zinc and lead in parts of Rajasthan and Bihar and several other centres bear testimony to the existence of flourishing and vigorous metal industries of the past. The famous iron pillars forged of remarkably pure and rustless iron, like the one (23 feet long) at Kutab Minar, near Delhi, which dates back to 415 A.D., the period of King Chandragupta II. and the steel used for Damascus swords,

are well-known examples of the art of ancient Indian Metallurgy. Minerals like coal, oil, chrome-ore, manganese, mica, ilmenite, etc., were altogether untouched till almost the end of the 18th century, when the impressive development of the Western World brought these minerals to the notice of European capitalists, who started large scale operations for mining these minerals for the purpose of export. In most cases the existence of old workings guided these explorations and development.

From the schematic diagrams representing the relative proportions of the various elements in the earth's crust, it may be easily understood why the silicates are predominating as rock-forming minerals, and amongst them quartz (SiO_2) is the most common and widely distributed.



EARTH SHELLS



WEIGHT CONTENT OF ELEMENTS IN THE EARTH'S CRUST

CHAPTER VII : ENGINEERING GEOLOGY

The utilization aspects of geological knowledge in the field of Civil Engineering may be listed as follows :

(i) It gives a systematic knowledge of materials, their occurrence and properties and helps the engineer in the selection of suitable materials for construction works.

(ii) It helps to tackle foundation problems which are directly geological.

(iii) It also helps in adopting proper methods of excavation.

(iv) From geological details groundwater occurrences are easily known which thus helps in various projects such as sanitary engineering, water supply, land drainage, irrigation and many other works.

(v) It makes him aware of surface waters and their methods of erosion and thus helps him in the execution of such works as river control, coastal and harbour works, soil conservation, etc.

(vi) It makes him read and interpret geologic reports, maps and photographs.

(vii) It familiarizes him with the processes of nature and thus enables him to carry out his works successfully and safely.

It may be concluded thus, that in any project safety and economy are the two main requirements and a civil engineer will be able to fulfil the same, if he utilises the different aspects of geological knowledge mentioned above.

CHAPTER VI INDIAN STRATIGRAPHY

In India, the oldest pre-Cambrian rock-formations (Archaeans and Dharwars) contain many metalliferous and non-metallic mineral deposits like those of iron ore, manganese ore, gold, copper ore, vanadium ore, chromite, mica, corundum, kyanite, sillimanite, graphite, dolomite, magnesite, asbestos, soapstone, kaolin, marbles, granites, and atomic enegry minerals.

In the later pre-Cambrian formations (Cuddapahs and Vindhyans), the Cuddapahs contain valuable deposits of marble, limestone, dolomite, slate, barite, asbestos, soapstone, mica, iron ore, lead-zinc ore, copper ore, kaolin and chert, and the Vindhyans contain valuable deposits of limestone, sandstone, diamond, pyrite, glass sand and ochre.

In the Palaeozoic (primary) group of geological formations, the uppermost system (Permian) is the most important formation from the point of view of mineral wealth. It contains the chief coal measures of India (Lower Gondwana coals), fire-clay sideritic and limonitic iron ore, sandstone, glass sand and china clay.

The Mesozoic (secondary) group of formations contains valuable deposits of limestone, sandstone, red shale, thin coal seams, chalk, gypsum, phosphatic nodules and celestite. The Deccan Trap and Rajmahal basalts supply valuable road metal and rail ballast, and contain in their cavities minerals like calcite, zeolite, quartz, amethyst, agate and other semi-precious varieties of silica.

The tertiary group of geological formations is important for deposits of gypsum, salt, lignite, petroleum, bauxite, limestone, sandstone, clay and gravel.

The Quaternary (Pleistocene and recent) formations are worked for building stone, laterite, bauxite, iron ore, manganese ore, ochres, lithomarge, brick clay, sand, gravel, kankar, calc-tufa, saltpetre, salt, 'reh' (sodium sulphate and carbonate) and placer deposits of gold, diamond, monazite, ilmenite and zircon.

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A TEXTBOOK OF GEOLOGY

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Our responsibility for industrialisation to build a new India, has tremendously increased, calling for the nation's entire effort and tapping of all available resources. A proper understanding of the subject of geology by the engineers and technologists will greatly help to play a major part in the successful exploitation and conservation of our country's mineral resources.

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